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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

Vol. CXXII.

EDITED BY

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CORRIGENDA.

Vol. cxx. p. 288. Tilbury Docks. It should have been stated that Messrs. Kirk and Randall were the original contractors for these works.

Vol. cxxi. p. 158, line 12, *for* "2407" *read* "2000."

„ p. 164 „ 3 from bottom, *insert* "+" *after* "refraction."

„ p. 190 „ 8, *for* "indentions" *read* "indentations."

„ p. 195 „ 8, *for* "1890" *read* "1880."

„ p. 307 „ 15 from bottom, *for* "18 inches" *read* "18 feet."

„ p. 349, lines 21 and 22, *for* "difference of level between the upper surface of the rails and the roof of the tunnel" *read* "height of the hill over the upper surface of the rails."

„ „ line 24, *for* "the roof" *read* "it."

Vol. cxxii. p. 203, line 12 *should read* "districts of Queensland a wooden sleeper costs from 7*d.* to 9*d.* delivered on the line," &c.

„ „ „ 13, *after* "sleeper" *add* "this price including freight from England and 25 per cent. *ad valorem* duty."

„ p. 204, line 14 from bottom, *for* "cast-iron" *read* "cast-steel."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1894–95.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS.

19 March, 1895.

Sir BENJAMIN BAKER, K.C.M.G., Vice-President, in the Chair.

(*Paper No. 2854.*)

"Steam-Engine Economy: Condensing-Engines."

By HENRY DAVEY, M. Inst. C.E.

THE principles which have governed the development of the steam-engine as regards economy of steam were well understood in the time of James Watt, who showed that gain might be expected to result from increased expansion, and invented some ingenious devices for securing that result. He also explained that in order to obtain the full benefit of expansion the cylinder must be maintained at a high temperature. Trevithick, Sims, and others perceived that increased expansion, and consequently greater economy, might result from the employment of higher pressures; whilst Grose succeeded in working engines with increased expansion, and introduced and perfected a system of clothing steam-pipes, cylinders, nozzles, and other parts of engines from which heat might escape by radiation.

As early as 1844 the Cornish engine was, for the steam-pressure then practicable, a more efficient engine than any other that has been produced subsequently. By the term "efficiency" the Author means the actual power developed compared with the power theoretically possible under the given conditions of initial pressure and expansion. Some Cornish engines at that time produced one I.HP. per hour for a consumption of 19 lbs. of steam at a boiler-pressure of 30 lbs. per square inch. Their efficiency was thus greater than that of modern triple-expansion engines giving one I.HP. per hour with 13 lbs. of steam at a pressure of 120 lbs. per square inch in the boiler.

The triple-expansion engine is more economical because it is worked at a higher pressure and at a higher rate of expansion;

but it does not utilize the pressure and expansion so efficiently as the Cornish engine did. A period of sixty-seven years has been required for the development of the principles enumerated by Watt, Trevithick, and Grose; and upwards of forty years have been required for the reduction of the consumption of steam from 19 lbs. to 13 lbs. per I.HP. per hour, or, in other words, for the diminution of the coal bill by one-third. In these advances no new principle has been applied, and no higher efficiency has been obtained. The progress has resulted from the labours of designers and makers of steam-engines—purely scientific investigation having only explained what the steam-engine should do if it worked in a manner wholly imaginary; whilst no one has shown how the ideal engine is to be constructed.

Such investigation may lead to practical results in the future, but for the present engineers must consider the steam-engine cycle as it exists, and a simple analysis of the working of the machine is sufficient to show how far it falls short of practical perfection, and what improvement upon it may be reasonably expected. It has become so usual of late years to associate the ideal with the real engine, that the steam-engine has come to be regarded as a very imperfect prime-mover; but if observation is confined to the actual steam-engine cycle, it is seen that in reality a properly constructed steam-engine is a highly efficient prime-mover. It gives a high efficiency under favourable conditions; the loss results from causes which are unavoidable, the effects of which can only be minimised. The proposal of Watt to use steam expansively, or to employ steam-jackets, was not the result of abstruse investigation on his part, but was due to the exercise of his strong common-sense or genius. Watt, from experience, knew enough of the properties of steam to appreciate without further investigation the fact that economy could be secured by working expansively, and that loss in the expansive force of the steam would result from the cooling action of the cylinder. Hence he saw that the steam ought to be protected as much as possible from such cooling action. A practical method of effecting that object was to keep the cylinder hot. If the various stages are traced in the development of the steam-engine since Watt's time, it will be found that the changes have been due to the exercise of that practical genius which embraces in its view considerations often beyond the range of theoretical investigation.

An engine which, from one point of view, is not the most perfect machine, may be the best for its purpose when all the circumstances of its application are considered. In the early days of the steam-

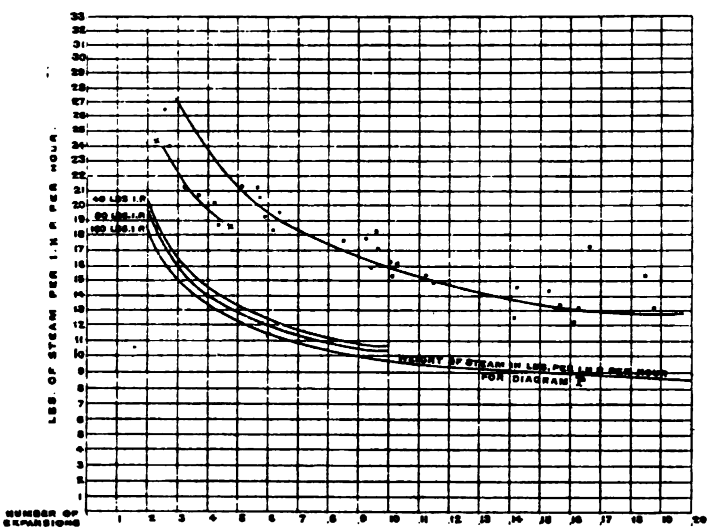
engine, the boiler and engine were tested together, and their duty was expressed in units of work developed per cwt. of coal consumed. Such a statement was of commercial as well as of scientific value. It has since become usual to test the engine and the boiler separately, but the old method has much to recommend it from the user's point of view. In order to obtain high economy of steam in the engine, a very high steam-pressure may be required; and to obtain that pressure with safety, an uneconomical boiler may be employed. In such a case the combined economy would be lower than that which might be secured by the boiler and engine together working at much lower pressure.

As early as forty years ago, Cornish boilers capable of evaporating 10 lbs. of water per lb. of Welsh steam coal were made, and were used for supplying steam to Cornish pumping-engines, producing one I.HP. per hour with a consumption of 1·8 lb. of Welsh coal, at a boiler-pressure not exceeding 40 lbs. per square inch. The weight of steam per I.HP. per hour does not always represent the true economy of the engine, because it may be that, in order to secure the highest economy, the size, friction, first cost, and cost of maintenance of the engine have been largely increased.

Compound Cornish engines were constructed as early as 1845, but it was found that with the boiler-pressure then available, viz., 40 lbs. per square inch, no better duty was obtained from them than from the single-cylinder engines. The compound engine became a success when higher boiler-pressure and therefore greater ranges of expansion became practicable, and the triple-expansion engine succeeded the compound engine in the same way. There are well-known practical reasons for increasing the number of cylinders at higher pressures and greater ranges of expansion. In order to determine the relative efficiencies of different types of engines it is necessary to have a standard of comparison. The efficiency of a steam-engine may be expressed by the number of units of heat expended to develop a given quantity of work, but in practice such a statement affords no measure of the quality of the machine as a steam-engine, because in it the conditions under which the engine works are not considered. Higher pressure and greater range of expansion produce greater economy, other things being equal. Therefore, in comparing the construction of one steam-engine with that of another, a basis of comparison must be established which will show how the other conditions vary if they are not equal, and it is with the object of drawing such a comparison that the Paper has been prepared.

The Author has collected the results of a considerable number of engine trials, and has submitted them to analysis with the object of comparing the consumption per I.HP. of different types of condensing-engines, and of directing attention to the causes which operate to make one engine more economical than another. The upper curve in *Fig. 1* is drawn through the points plotted from the actual engine-trials under consideration, and shows the weight of steam per I.HP. per hour used at the different ratios of expansion employed. The initial pressure is given, and, as a standard for comparison, the lowest curve is drawn to represent the weight of steam which would be required, if the expansion curve of the

Fig. 1.

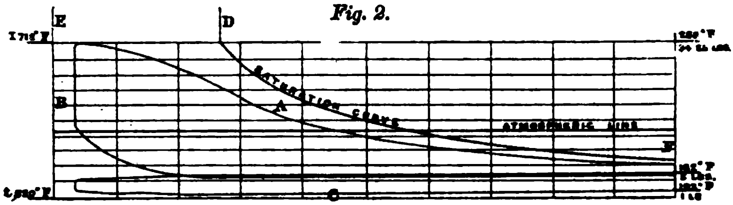


indicator-diagram is assumed to be that of saturated steam, without loss from clearance and back-pressure.

The mean indicator-card of a given trial having been selected, the length E D, *Figs. 2, 3, 4* and *5*, is laid off to represent the weight of steam used per stroke, and a saturation curve D F is delineated to represent an assumed standard for a jacketed engine, working with the steam-engine cycle, and with no losses. This figure having been completed, the losses which make up the difference between the actual and the standard diagram can be readily localized, and their relative importance ascertained. Calling the mean pressure of the indicator figure p and that of the

standard engine diagram P, the Author expresses the "engine-efficiency" as $\frac{p}{P}$. The diagrams being drawn to a scale convenient

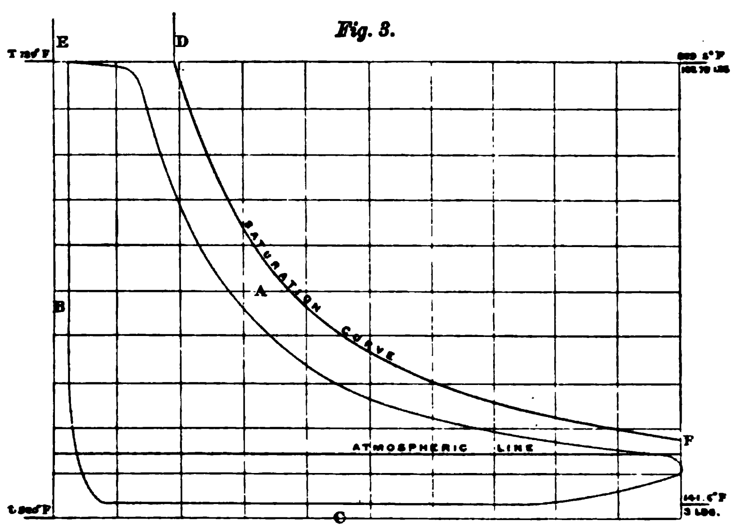
Fig. 2.



			Per cent.
Efficiency			71·0
		Per cent.	
Losses . .	A	15·2	
" . .	B	8·9	29·0
" . .	C	4·9	
			100·0

CORNISH.

Fig. 3.



			Per cent.
Efficiency			68·4
		Per cent.	
Losses . .	A	17·9	
" . .	B	4·8	31·6
" . .	C	8·9	
			100·0

SINGLE-CYLINDER ROTATIVE.

for the use of the planimeter, the area of the waste spaces, indicated by A, B, and C in the *Figs.*, can be measured and expressed

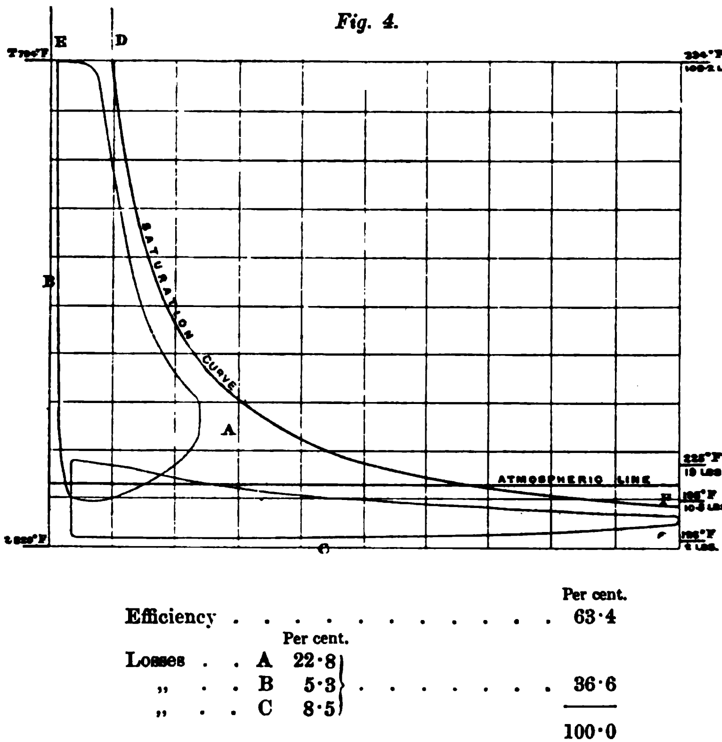
as a percentage of the full total of the diagram. These waste spaces represent:—

A. Cylinder-condensation, &c. (This waste includes condensation in the jacket.)

B. Clearances. (Compression influences, if considerable, should be taken into account.)

C. Back-pressure.

Fig. 4.



				Per cent.
Efficiency				63·4
		Per cent.		
Losses	A	22·8		
„	B	5·3		36·6
„	C	8·5		
				100·0

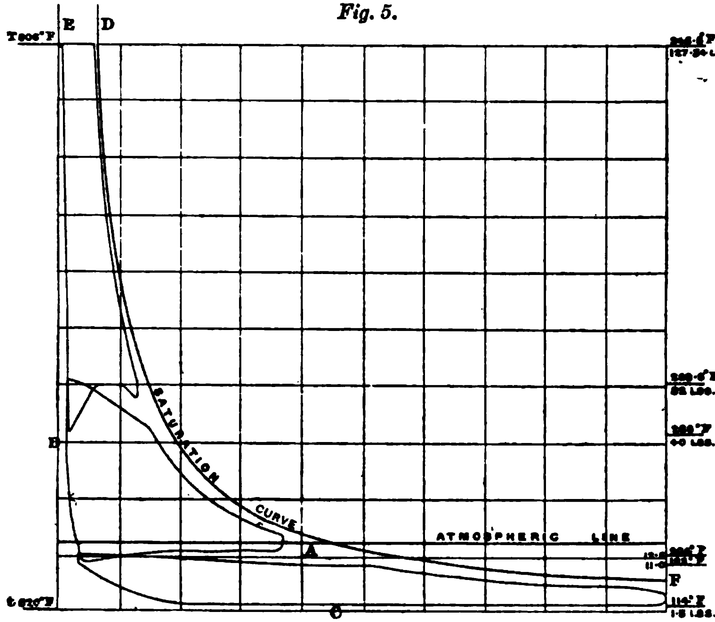
COMPOUND.

The mean indicator-cards of a considerable number of trials have been analysed by this method, and the results are recorded in Table II, Appendix I.

The numbers in the third column show the initial steam-pressure, and those in the fourth the average pressure from the indicator-diagrams referred to the low-pressure cylinder. In the fifth column are given the ratios of expansion calculated from the

weight of steam admitted to the cylinder per stroke, including jacket-water. The sixth shows the engine-efficiency or $\frac{p}{P}$, and the last three columns give the engine losses A, B, and C. The ratio of expansion is seen to increase from 2·83, in the first example of the Cornish series, to 18·53 in the last example of the triple-

Fig. 5.



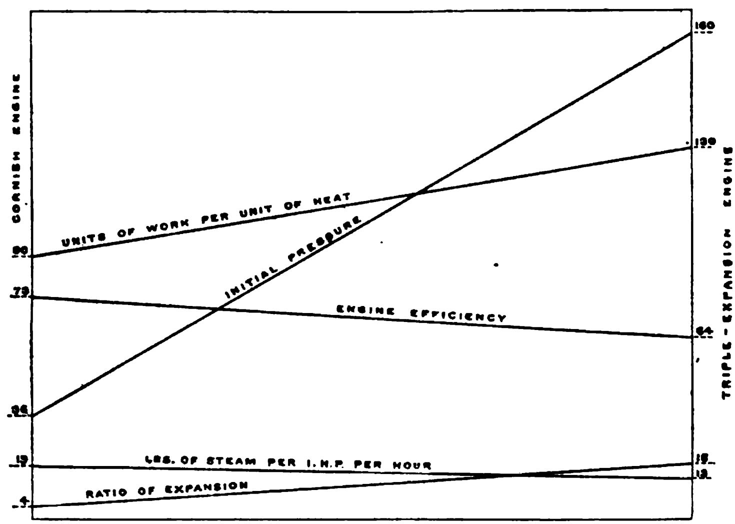
		Per cent.		Per cent.
Efficiency				70·5
Losses	A	14·9	}	29·5
"	B	6·6		
"	C	8·0		
				100·0

TRIPLE-EXPANSION.

expansion series. The initial pressure also increases from 31 lbs. per square inch in the first of the Cornish series to 142 lbs. per square inch in the last example of the triple-expansion series. The examples have been collected with the object of obtaining an average result from a variety of engines, and without any attempt at uniformity. Most of the examples have been taken from published sources, others from the Author's experiments, and

the average results may be taken as fairly accurate, and good comparisons may be made with some of the individual trials. The advance which has taken place in steam-engine economy, and the causes which have contributed to that advance, will be readily appreciated by reference to *Fig. 6.* On the left-hand side of the *Fig.* are shown the conditions which existed in the Cornish engine more than forty years ago, and on the right-hand side the conditions as they exist in the modern triple-expansion engine. The initial pressure has been raised from 36 lbs. to 160 lbs. per square inch, the engine-efficiency has diminished from 73 per cent. to 64 per cent., the consumption of

Fig. 6.



steam per I.HP. per hour has also diminished from 19 lbs. to 13 lbs. per square inch, whilst the ratio of expansion has been increased from 4 to 18. Details of these conditions in the engines considered are given in Table II, Appendix I. The principal loss A is almost wholly due, in the simple engine, to cylinder-condensation and radiation; but in the compound and triple-expansion engines it is made up of cylinder-condensation, radiation, loss of pressure between the cylinders, and friction in the ports and valves between the cylinders. The average total loss A amounts to 20 per cent. in the compound and 21 per cent. in the triple-expansion series, and it may be assumed that 5 per cent. of this is due to losses other than

cylinder-condensation. The actual loss from cylinder-condensation is therefore only 15 per cent., and if the examples of steam-jacketed engines alone were considered, it would be found to be less. The loss from cylinder-condensation alone will be observed to be nearly the same in Cornish, compound, and triple-expansion engines, but it is lowest in the best examples of the latter. Cylinder-condensation results not only from the cooling influence of the cylinder-walls, but also from the loss of heat due to the production of work for which 2,500 units of heat are required per I.HP. per hour. When this conversion of heat into work is considered, a smaller part of the loss of heat is seen to be accounted for by the cooling influence of the cylinder-walls. Economy would result from superheating the steam, and the area of the indicator-card might be increased, especially if the waste heat of the boiler were used to supply the additional heat. Superheating was the device of the engineer thirty years ago, but practical difficulties led to its abandonment. The problem is now entirely a practical one. Any addition of heat to the steam tends to increase economy by increasing the engine-efficiency. The engine-efficiency generally increases with the average pressure, and the economy increases with the ratio of expansion and with the average pressure. The mechanical efficiency will generally also increase with the average pressure. It is the result of experience that a terminal pressure of 10 lbs. per square inch, calculated from the weight of steam per stroke, is a most economical condition; that is to say, steam of 160 lbs. per square inch initial pressure should be expanded sixteen times, and steam of 100 lbs. per square inch pressure should be expanded ten times to obtain the best practical result. This rule must not, however, be regarded as universal, for it may require qualification to meet important special conditions which must often be taken into account. Referring to Table I, Appendix I, it will be seen that the engine-efficiency $\frac{p}{P}$ varies in some cases considerably from that given in Table II. This is probably on account of the indicator-cards analysed being not always the true mean cards, and there are possible errors arising from the fact that in some cases the cards had been reproduced. It will, however, be seen that the average results in the two Tables do not differ very materially. There are also small errors due to the fact that the weight of steam was ascertained in some cases from the boiler-feed, and in other cases from the condenser-discharge; and there may also be slight errors in the planimeter readings. With regard to the last column in Table I, the units of heat are taken from the

heat of the steam, and not from the heat of the feed-water, as it would have been taken if the temperature of the feed-water had been observed in all cases.

In *Fig. 2*, D is called the point of cut-off, as it is the point at which the steam would have been cut off if it had remained in a saturated state without initial condensation and without priming water. This point determines the volume of saturated steam delivered into the cylinder per stroke. If this mode of analysis is adopted, the results of an engine trial may be tabulated in the manner shown for the four examples:—*Fig. 2*, Cornish; *Fig. 3*, single-cylinder rotative; *Fig. 4*, compound; *Fig. 5*, triple-expansion. Particulars of these trials are given in Appendix II.

From such results of a number of engine-trials, the relative economies of the various engines under consideration may be readily ascertained. The most convenient mode of comparing the general results is to plot on a curve, *Fig. 1*, the weight of steam per I.HP. per hour which would be required if the engine were assumed to work in such a manner as to give the diagram represented by P, and to plot above the curve thus produced the actual steam used as ascertained by engine-trials. The rates of expansion are derived, as explained above, not from the points of cut-off shown in the actual diagrams, but from those which would have been shown if the steam had remained in a saturated state until the point of cut-off. These curves demonstrate that, as the boiler-pressure and the ratio of expansion are increased, other things being equal, the economy is increased.

The engine-efficiencies $\frac{p}{P}$ shown in *Fig. 1*, and in Tables I and II, Appendix I, cover all ranges of expansion between 2 and 18 for the Cornish, marine, compound and triple-expansion types of engines. The higher engine-efficiency is chiefly due to diminished cylinder-condensation resulting from steam-jacketing, clothing, compounding, and the use of the Cornish cycle. Without the aid of such an analysis of the engine diagrams as that given in Table II, it would be difficult to discover the cause of small differences. For example, in comparing two trials between which there is a difference of only 5 per cent. in the steam economy, it may be found that there was, during the trials, a difference of 5 per cent. between the back-pressures, or between the rates of expansion.

The Cornish cycle was devised for pumping-engines in the early days of the steam-engine in Cornwall. Its effect is to maintain the working portion of the cylinder at a higher temperature than it would have if the steam were discharged directly into the

condenser. It reduces initial condensation, and by this means increases the engine-efficiency. The Cornish engine shows the highest engine-efficiency, but it has become obsolete with the adoption of high-pressure steam, and of other less cumbersome engines giving superior economy. It embodied, however, the principles of the most advanced modern steam-engine practice.

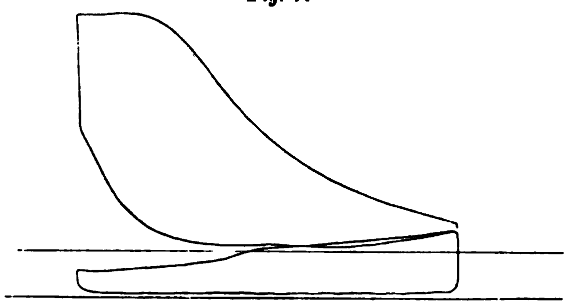
The greater economy of more recent engines has resulted from the use of higher pressure and greater range of expansion. The compound engine utilizes the principle of the diminution of the range of temperature in the cylinder which is embodied in the Cornish cycle, but the triple-expansion engine does so to a much larger extent. In the compound engine, the loss represented by A is larger with the Woolf distribution of steam than with the receiver engine, because in the Woolf engine the cylinders are subjected to a greater range of temperature, and there is greater loss of pressure between the cylinders. In the case of example No. 17 of the triple-expansion series, Table II, the loss A is about one-half of the total loss, or say 14 per cent. of the power represented by the standard diagram. The losses B and C each amount to about 7 per cent., so that the total average efficiency is about 70 per cent. The losses B and C are nearly constant in well-made engines, and therefore the remaining loss A of 14 per cent. is the only one which admits of considerable reduction, unless it can be shown that the diagram represented by P shows too low a standard.

Pumping-engines, notwithstanding the low speed at which they work, have always been among the most economical of steam-engines. It has been stated above that the Cornish engine, which is a non-rotative engine, gives a higher engine-efficiency than any other. The limit of its economy has, however, been reached, because it cannot be worked at a higher steam-pressure nor with a greater ratio of expansion. The Author read a Paper[1] before this Institution in 1878, on an engine which, although non-rotative, enabled a higher pressure of steam and higher rates of expansion to be employed. Since that time it has become possible to employ in non-rotative engines the high pressure and high rates of expansion which are now used in rotative engines, each cylinder of the compound or triple-expansion engine having an early cut-off effected by separate cut-off valves, as illustrated by the compound-engine diagram, *Fig. 7*. The direct-acting non-rotative engine in its simplest form, namely, that of the simple compound and triple steam-pump, has had a wide application. Such engines

[1] Minutes of Proceedings Inst. C.E., vol. liii. p. 98.

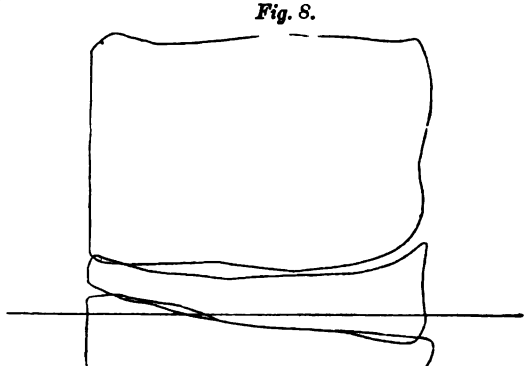
are founded on the principle of what may be called stage-expansion, illustrated in *Fig. 8*. There is a large fall in pressure between one cylinder and the next, and the engine-efficiency is consequently very low. The compound non-rotative engine, working with considerable range of expansion in each cylinder,

Fig. 7.



as illustrated in *Fig. 7*, has been found to give an economy of 16 lbs. of steam per I.HP. per hour at 70 lbs. per square inch boiler-pressure, and an engine-efficiency of 64 per cent. The engine-efficiency to be obtained from a given distribution of steam affords a proper gauge of the value of the engine in point of possible economy.

Fig. 8.



The economy of a compound engine with a cylinder-ratio of 7 to 1 has recently been discussed by the American Society of Mechanical Engineers. The point at issue was whether the engine gave as high economy as a triple-expansion engine would have given under the same conditions as to steam-pressure

and expansion—in other words, what was its engine-efficiency? From the published indicator-cards it appears that the engine-efficiency, deduced by the Author's method, was 61·2 per cent., and the losses—

	Per cent.
A	21·9
B	6·7
C	10·2
	38·8

An attempt was made in the discussion to compare the economy of this engine with that of the triple-expansion engine No. 16, in Tables I and II, Appendix I. It will be seen that the engine-efficiency of this example was 74·8, and the losses were:—

	Per cent.
A	8·7
B	4·2
C	12·3
	25·2

The losses B and C together amount to practically the same for both engines; but in the case of the compound engine the loss A was 21·9 per cent. as compared with 8·7 per cent. in the case of the triple-expansion engine. It will, however, be observed, by reference to the Tables, that 8·7 is an abnormal result. In the case of the compound engine there was considerable drop in pressure between the cylinders, which contributed to the loss A.

The Author has found the method of analysis set forth in the Paper of considerable practical utility in dealing with the results of engine-trials. For example, a trial was made of a compound engine having an initial pressure of 90 lbs. per square inch, and a terminal pressure of 9 lbs. per square inch. The weight of feed-water per I.HP. per hour was found to be 19 lbs. On analysing the diagrams, the efficiency was found to be about 50 per cent., whilst the losses were—

	Per cent.
A	35·40
B	7·70
C	6·67
	49·77

The bodies of the cylinders were jacketed, but the cover was not. The Author then examined the engine to ascertain why the loss A

was so large, and he found that the drain-cocks of the cylinders were broken inside and that steam was passing through them in large quantities.

The Author has shown that the Cornish cycle possesses considerable economical effect. It is supposed that initial condensation increases with the surface of the cylinder-walls and the fall in temperature to which the walls are exposed. On that

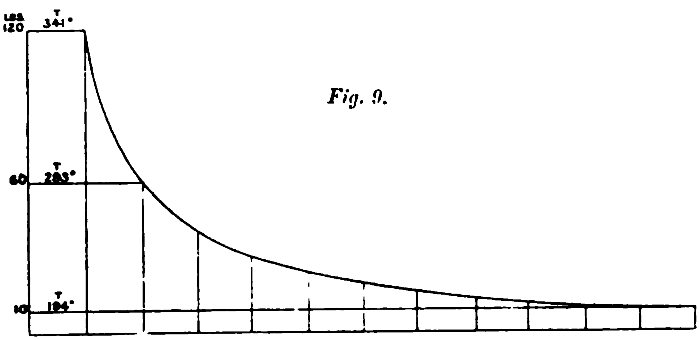


Fig. 9.

H.P. fall in temperature 48°; L.P. fall in temperature 96°.

COMPOUND CORNISH CYCLE.

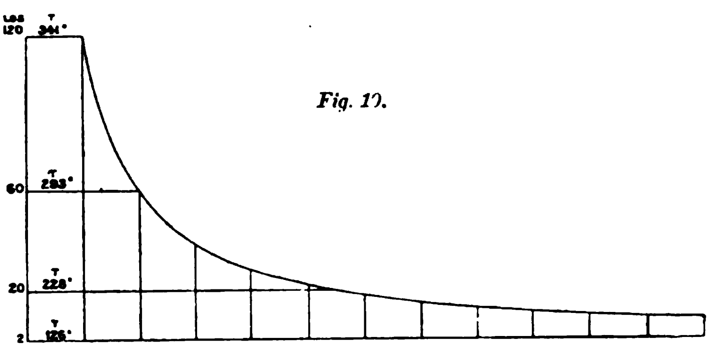


Fig. 10.

H.P. fall in temperature 48°; I.P. fall in temperature 65°; L.P. fall in temperature 102°.

TRIPLE-EXPANSION.

assumption, a comparison can be instituted between the values of initial condensation in different types of engines without the actual values being known.

Selecting as examples :—1st, a triple-expansion engine having cylinder-ratios 1 to 2·5 to 6; 2nd, a compound engine having cylinder-ratio 1 to 6; 3rd, a compound Cornish cycle engine having cylinder-ratio 1 to 6; and 4th, a single-cylinder engine.

Let the low-pressure cylinder in each case be 36 inches in diameter by 3 feet stroke, the initial pressure 120 lbs. per square inch, and the ratio of expansion 12. Multiplying the areas of the surfaces into the fall in temperature to which they are exposed in each cylinder, and adding the results together for each engine, the following relative values are given:—

Compound Cornish cycle	1·00
Triple-expansion	1·34
Compound	1·50
Single-cylinder	1·87

The cylinder-ends and the piston contribute, relatively, more to initial condensation than do the other parts of the cylinder. By

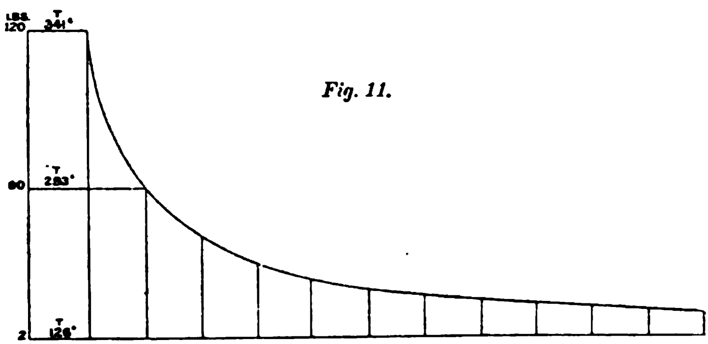


Fig. 11.

H.P. fall in temperature 48°; L.P. fall in temperature 167°.

COMPOUND.

confining the calculation to the ends and pistons only, the following values are obtained:—

Compound Cornish cycle	1·00
Triple-expansion	1·28
Compound	1·63
Single-cylinder	2·01

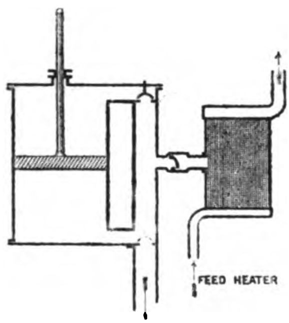
The results are shown graphically in *Figs. 9, 10,* and *11.*

The Cornish cycle might be made to give increased economy by a method which appears to have hitherto escaped notice. The steam, which has done its work and has passed the equilibrium-valve, possesses considerable pressure and temperature, say a pressure of 10 lbs. per square inch and a temperature of 194° F. If a connection having a non-return valve were made to a feed-water heater from the equilibrium-pipe, as shown in *Fig. 12,* the feed-

water could be heated to, say, 180° F., on its way to the boiler. This possible element of economy invests the Cornish cycle with additional importance in connection with the question of steam-engine economy.

It has been shown that the compound Cornish cycle engine is superior to the others, in suffering a smaller loss from initial condensation, and it might be made to effect a saving of 6 per cent. of steam by heating the feed-water to a higher temperature

Fig. 12.



than that possible with other engines. Taking all things into consideration, the Author is of opinion that this engine, combined with a feed-water heater, will be found to be between 8 per cent. and 10 per cent. more economical per actual HP. than the triple-expansion engine.

The Paper is accompanied by eleven sheets of diagrams, from which the *Figs.* in the text have been prepared.

[APPENDIX.

APPENDIX I.

TABLE I.—STEAM-ENGINE TRIALS.

Type of Engine.	Reference Number of Trial.[1]	Initial Pressure.	Ratio of Expansion.	Lbs. of Steam per I.H.P. per Hour.	Engine-efficiency $\frac{p}{P}$	Units of Work per Unit of Heat.
					Per cent.	
Cornish	2	31 J	2·83	24·00	71·3	68·7
„	52	27 J	3·12	21·38	78·8	80·1
„	55	34·25 J	3·87	20·72	71·1	76·9
„	53	40 J	4·17	20·08	72·0	84·8
„	54	36 J	4·28	18·82	76·0	90·6
Averages	..	33·65	3·65	21·00	73·8	80·2
Single-cylinder rotative	1	34 J	2·63	26·69	69·8	65·0
„ „ „	1a	36 N	2·84	32·14	60·8	53·8
„ „ „	60	105·79 N	4·76	20·37	67·0	85·7
„ „ „	58	104·77 N	4·93	19·15	65·9	89·03
„ „ „	59	102·79 N	5·13	19·22	69·0	88·7
Averages	..	76·67	3·95	23·51	66·5	76·44
Marine compound	3	77·5	4·96	21·73	64·4	78·11
„ „	4	66·5	5·33	21·17	61·0	78·8
„ „	5	108·0	5·71	20·77	60·1	81·0
Three-cylinder compound	6	91 J	6·06	18·11	68·7	93·5
„ „ „	6a	91 N	5·98	19·15	66·0	71·7
Rotative „	7	78 J	6·36	19·52	65·4	90·0
„ „	7a	75 N	5·62	21·06	62·6	88·8
Non-rotative „	57	72·2 J	9·17	17·70	63·0	96·8
Rotative „	8	102 J	9·48	15·90	66·0	106·1
„ „	8a	99 N	8·61	17·67	60·2	95·5
„ Beam „	10	60 J	10·08	16·64	66·0	102·1
„ „ „	10a	64 N	9·5	18·20	62·1	92·8
„ „ „	56	109·2 J	10·16	16·24	64·0	103·6
Horizontal non-rotative compound	11	87·0 J	11·3	15·6	65·4	110·8
Averages	..	84·3	7·73	18·53	63·9	92·11
Rotative triple-expansion	9	127 J	10·07	15·370	68·4	108·80
„ „	9a	129·5 N	9·54	17·170	61·3	97·60
Marine „	12	137·5	11·60	19·830	50·7	84·84
„ „	13	154·0	11·60	14·970	68·2	111·00
Land „	14	161 N	14·18	12·510	76·2	136·08
Pumping „	15	128·5 J	15·30	14·240	63·9	117·40
„ „	15a	126 N	14·40	14·690	64·0	113·80
„ „	16	132·7	16·14	12·155	72·6	137·30
„ „	17	127·5 J	16·30	13·160	69·2	127·80
„ „	17a	126·5 N	15·60	13·470	67·8	124·10
Marine „	19	164·5	18·90	13·350	62·9	125·10
Pumping „	18	142 J	18·53	15·450	59·5	108·20
„ „	18a	142 N	16·50	17·220	53·4	97·20
Averages	..	138·3	14·51	14·880	64·4	114·55

NOTE.—J and N in col. 3 indicate jacketed and non-jacketed respectively.

[1] See Table III.

TABLE II.—ANALYSIS OF INDICATOR-CARDS.

Type of Engine.	Reference Number of Trial.[1]	I. P.	A. P.	Ratio of Expansion.	$\frac{p}{P}$	Losses. A	Losses. B	Losses. C
					Per cent.	Per cent.	Per cent.	Per cent.
Cornish	2	31 J	15·70	2·83	70·0	15·0	6·0	9·0
„	55	34·25 J	14·80	3·87	71·0	15·2	8·9	4·9
Averages . . .	..	32·62	15·20	3·35	70·5	15·1	7·45	6·95
Single-cylinder rotative	1	34 J	17·46	2·63	71·5	..	..	..
„ „ „	1a	36 N	17·13	2·34	61·1	..	..	..
„ „ „	60	105·79 N	37·00	4·76	66·8	20·2	6·2	6·8
„ „ „	58	104·77 N	36·40	4·93	66·4	23·0	4·1	6·5
„ „ „	59	102·79 N	34·50	5·13	68·4	17·9	4·8	8·9
Averages . . .	..	76·67	28·49	3·95	66·8	20·3	5·0	7·4
Marine compound . .	3	77·5	24·80	4·96	60·7	18·7	7·2	13·4
„ „ . .	4	66·5	19·90	5·33	59·7	20·3	7·3	12·7
„ „ . .	5	108	30·17	5·71	54·4	20·1	14·1	11·4
Three-cylinder compound	6	91 J	28·19	6·06	67·8	16·0	7·1	9·1
„ „ „	6a	91 N	27·08	5·98	64·3	21·5	6·5	7·7
Rotative compound .	7	78 J	22·23	6·36	66·0	17·6	7·7	8·7
„ „ .	7a	75 N	22·04	5·62	62·0	21·5	6·2	10·3
Non-rotative compound	57	72·2 J	15·13	9·17	62·7	23·0	3·5	10·0
Rotative compound .	8	102 J	22·07	9·48	66·6	17·3	5·5	10·6
„ „ .	8a	99 N	21·28	8·61	61·4	22·2	4·7	11·7
„ beam compound	10	60 J	12·45	10·08	61·4	15·2	7·3	16·1
„ „ „	10a	64 N	12·80	9·50	56·2	22·3	6·7	14·5
„ „ „	56	109·2 J	21·78	10·16	63·4	22·8	5·3	8·5
Horizontal non-rotative compound. . . .	11	87 J	17·00	11·30	67·2	11·9	9·6	11·3
Averages . . .	..	84·3	21·20	7·73	62·4	19·3	7·0	11·1
Rotative triple-expansion	9	127 J	27·36	10·07	59·0	26·0	8·4	6·6
„ „	9a	129·5 N	26·37	9·54	57·4	24·4	9·1	9·1
Marine „	12	137·5	19·80	11·60	49·1	28·1	11·4	11·4
„ „	13	154	30·30	11·60	63·2	12·4	15·4	9·0
Land „	14	161 N	30·07	14·18	70·6	14·3	7·7	7·4
Pumping „	15	128·5 J	19·18	15·30	64·6	22·2	6·6	6·6
„ „	15a	126 N	19·22	14·40	64·7	22·5	5·9	6·9
„ „	16	132·7	21·57	16·14	74·8	8·7	4·2	12·3
„ „	17	127·5 J	19·24	16·30	70·5	14·9	6·6	8·0
„ „	17a	126·5 N	19·39	15·60	69·9	16·3	5·6	8·2
Marine „	19	164·5	21·13	18·90	60·1	16·5	18·3	5·1
Pumping „	18	142 J	16·30	18·53	53·1	31·4	8·1	7·4
„ „	18a	142 N	16·46	16·50	49·8	33·8	6·2	10·2
Averages . . .	..	138·3	22·03	14·51	62·0	20·88	8·73	8·32

NOTE.—J and N in col. 3 indicate jacketed and non-jacketed respectively.

[1] See Table III.

TABLE III.—REFERENCES TO TRIALS.

Reference Numbers.	—
1	Steam-Jacket Research Committee, Inst. Mech. Engs. (2nd Report). Trial by Prof. Unwin.
1a	Ditto.
2	Trial by Mr. Henry Davey of Engine at the Wolverhampton Waterworks.
3	Research Committee on Marine-Engine Trials, Inst. Mech. Engs (Proceedings, 1890). Trials by Dr. Kennedy.
4	Ditto.
5	Ditto. (Proceedings, 1892.)
6	Steam-Jacket Research Committee, Inst. Mech. Engs. (3rd Report). Trials by Mr. Bryan Donkin.
6a	Ditto.
7	Steam-Jacket Research Committee, Inst. Mech. Engs. (2nd Report). Trial by Prof. Unwin.
7a	Ditto.
8	Steam-Jacket Research Committee, Inst. Mech. Engs. (3rd Report). Trial by Prof. Beare.
8a	Ditto.
9	Steam-Jacket Research Committee, Inst. Mech. Engs. (3rd Report). Trial by Mr. Bryan Donkin.
9a	Ditto.
10	Steam-Jacket Research Committee, Inst. Mech. Engs. (2nd Report). Trial by Mr. Mair-Rumley.
10a	Ditto.
11	Trial by Mr. Henry Davey of Engine at the Widnes Waterworks.
12	Research Committee on Marine-Engine Trials, Inst. Mech. Engs. (1890). Trials by Dr. Kennedy.
13	Ditto. (1889.)
14	Trial by Mr. I. F. L. Crosland.
15	Steam-Jacket Research Committee, Inst. Mech. Engs., East London Waterworks (3rd Report). Trial by Messrs. Beare, Donkin, and Davey.
15a	Ditto.
16	Trial by Prof. R. H. Thurston.
17	Steam-Jacket Research Committee, Inst. Mech. Engs., East London Waterworks. Trial by Messrs. Beare, Donkin, and Davey.
17a	Ditto.
18	Steam-Jacket Research Committee, Inst. Mech. Engs. (2nd Report). Trial by Mr. Henry Davey.
18a	Ditto.
19	Research Committee on Marine-Engine Trials, Inst. Mech. Engs. (1891). Trial by Dr. Kennedy.
52	Clark's "Steam Engine," vol. ii. p. 509, East London Waterworks. Trial by Mr. C. Greaves.
53	Ditto.
54	Ditto.
55	Ditto.
56	Trial by Dr. Kennedy, *The Engineer*, August 29, 1890.
57	Trial by Prof. Unwin of Engines at West Middlesex Waterworks. *Engineering*, Dec. 7, 1888.
58	Trial by Mr. J. W. Hill, Cincinnati. Clark's "Steam Engine," vol. ii. p. 516.
59	Ditto.
60	Ditto.

APPENDIX II.

No. 55. Cornish. (See *Fig. 2.*)

Cylinder 72 inches diameter × 9·625 feet stroke.

P = Total average pressure for saturated steam	lbs. per sq. in.	20·8
p = " " from indicator-diagram	"	14·8
Engine-efficiency $= \frac{p}{P}$	per cent.	71·1
$\frac{W}{U}$ = Units of work per unit of heat		76·9

Data.—*Cylinder: stroke, 9·625 feet; diameter, 72 inches; area, 4,071·5 square inches. Jacketed.*

I = Initial pressure	lbs. per sq. in.	34·24
S = Specific volume (saturated steam)		741·0
p = Average pressure from indicator-diagrams	lbs. per sq. in.	14·8
F = Steam used per I.HP. per hour	lbs.	20·72
K = I.HP. per stroke		17·8
C′ = Steam used per stroke in lbs. $= \frac{K \times F}{60}$		6·146
U = Units of heat of steam per stroke		7,129·2
W = Units of work per stroke from indicator-cards		548,534·5
C = Cubic inches of steam used at pressure I per stroke, $C = (C' \times 27{\cdot}69 \times S)$		63,052·4
A = Area of cylinder	square inches	4,071·5
$a = \frac{C}{A}$ = period of admission (theoretical)	inches	15·46
S′ = Stroke of engine in inches + clearance (3·67 per cent.)		119·73
R = Ratio of expansion $= \frac{S'}{a}$		3·87
P = Total average pressure for saturated steam	lbs.	20·8

Limits of temperature of steam in cylinder from diagram = steam stroke, 258° F., 162° F.; equilibrium stroke, 161·5° F., 102° F.

No. 59. Single-Cylinder Rotative. (See *Fig. 3.*)

Cylinder 18·26 inches diameter × 4 feet stroke. No jacket.

P = Total average pressure for saturated steam	lbs. per sq. in.	50·0
p = " " from indicator-diagram	"	34·5
Engine-efficiency $= \frac{p}{P}$	per cent.	69·0
$\frac{W}{U}$ = Units of work per unit of heat		88·7

Data.—*Cylinder: stroke, 4 feet; diameter, 18·26 inches; area, 261·5 square inches.*

I = Initial pressure	lbs. per sq. in.	102·79
S = Specific volume (saturated steam)		262·75
p = Average pressure from indicator-diagrams	lbs. per sq. in.	34·5

F =	Steam used per I.HP. per hour	lbs.	19·22
K =	I.HP. per stroke		1·076
C' =	Steam used per stroke in lbs. $= \frac{K \times F}{60}$		0·344
U =	Units of heat of steam per stroke		406·6
W =	Units of work per stroke from indicator-cards		36,087·0
C =	Cubic inches of steam used at pressure I per stroke $C = (C' \times 27 \cdot 69 \times S)$		2,502·78
A =	Area of cylinder	square inches	261·5
a =	$\frac{C}{A}$ = period of admission (theoretical)	inches	9·57
S' =	Stroke of engine in inches + clearance (2·35 per cent.)		49·12
R =	Ratio of expansion $= \frac{S'}{a}$		5·13
P =	Total average pressure for saturated steam	lbs.	50·0

Limits of temperature of steam in cylinder from diagram = 329·5° F., 141·6° F.

No. 56. COMPOUND. (See *Fig. 4.*)

Cylinders 20 and 33·97 inches diameter × 47·9 and 71·8 inches stroke.

P =	Total average pressure for saturated steam	lbs. per sq. in.	34·0
p =	" " " from indicator-diagram	"	21·78
	Engine-efficiency $= \frac{p}{P}$	per cent.	64·0
$\frac{W}{U}$ =	Units of work per unit of heat		103·6

DATA.—*L.P. Cylinder: stroke, 71·8 inches; diameter, 33·97 inches; area, 901·26 square inches. Jacketed.*

I =	Initial pressure	lbs. per sq. in.	109·2
S =	Specific volume (saturated steam)		249·0
p =	Average pressure from indicator-diagrams	lbs. per sq. in.	21·78
F =	Steam used per I.HP. per hour	lbs.	16·24
K =	I.HP. per stroke		3·54
C' =	Steam used per stroke in lbs. $= \frac{K \times F}{60}$		0·958
U =	Units of heat of steam per stroke		1,133·0
W =	Units of work per stroke from indicator-cards		117,384·0
C =	Cubic inches of steam used at pressure I per stroke $C = (C' \times 27 \cdot 69 \times S)$		6,605·2
A =	Area of L.P. cylinder	square inches	901·26
a =	$\frac{C}{A}$ = Period of admission (theoretical)	inches	7·32
S' =	Stroke of engine in inches + clearance (3·6 per cent.)		74·38
R =	Ratio of expansion $= \frac{S'}{a}$		10·16
P =	Total average pressure for saturated steam	lbs.	34·0

Limits of temperature of steam in cylinders from diagrams = H.P. 334° F., 195° F.; L.P. 225° F., 126° F.

Relative capacities of cylinders . . . . 4·3 to 1

No. 17. TRIPLE-EXPANSION. (See *Fig. 5.*)

Cylinders 20·03 inches, 33·99 inches, 57·05 inches diameter × 4 feet stroke.

P = Total average pressure for saturated steam		lbs. per sq. in.	27·8
p = ,, ,, from indicator-diagram		,,	19·24
Engine-efficiency $= \frac{p}{P}$		per cent.	69·2
$\frac{W}{U}$ = Units of work per unit of heat			127·8

DATA.—*L P. Cylinder: stroke, 48 inches; diameter, 57·05 inches; area, 2551·76 square inches. Jacketed.*

I = Initial pressure	lbs. per sq. in.	127·5
S = Specific volume (saturated steam)		215·0
p = Average pressure from indicator-diagram	lbs. per sq. in.	19·24
F = Steam used per I.HP. per hour	lbs.	13·16
K = I.HP. per stroke		5·903
C' = Steam used per stroke in lbs. $= \frac{K \times F}{60}$		1·294
U = Units of heat of steam per stroke		1,535·4
W = Units of work per stroke from indicator-cards		196,383·0
C = Cubic inches of steam used at pressure I per stroke $C = (C' \times 27 \cdot 69 \times S)$		7,706·4
A = Area of L.P. cylinder	square inches	2,551·76
$a = \frac{C}{A}$ = Period of admission (theoretical)	inches	3·02
S' = Stroke of engine in inches + clearance		49·5
R = Ratio of expansion $= \frac{S'}{a}$		16·3
P = Total average pressure for saturated steam	lbs.	27·8

Limits of temperature of steam in cylinder from diagram.
H.P. 345·5° F., 268° F.; I.P. 283° F., 198° F.; L.P. 204° F., 114° F.

Relative capacities of cylinders + clearance . . . 1 to 2·97 to 8·33

[DISCUSSION.

Discussion.

Sir Benjamin Baker, K.C.M.G., Vice-President, said there were many works in the field of investigation covered by the Paper, but there was hardly any investigator entitled to speak with greater authority on the subject, on the basis of practical experience, than the Author. He had, therefore, great pleasure in asking the members to accord him a very hearty vote of thanks for his valuable Paper. Sir Benjamin Baker.

Mr. Henry Davey wished it to be clearly understood that when speaking, in the latter part of the Paper, of a Cornish cycle, he did not mean a Cornish engine. With reference to the mode of analysis of indicator-diagrams he had selected, any errors in the system which did not appear to have any material effect in vitiating the comparative results had been neglected. The object of the Paper was to make comparisons. In *Fig. 2* it would be seen that the enclosing diagram should be longer than the enclosed diagram; therefore the energy to be obtained from the enclosing diagram was measured, not only by the average pressure of the diagram, but by its length; and as it was longer than the indicator-diagram, if that error were corrected it would make what he had called the engine-efficiency somewhat lower. It would do so, however, in all the examples throughout the series, and it would not materially affect the comparative results. Again, he had pointed out that compression influences, when considerable, should be taken into account; but he had not thought it necessary to calculate all those influences, because the percentages would be similar throughout the series. He wished to emphasize the fact that the foundation of the Paper was a comparison of results. At absolute results he had not attempted to arrive. Mr. Davey.

Mr. Mark Robinson remarked that great interest attached to the comparisons made in the Paper between engines of different types; but he could not help calling in question the standard with which comparison had been made. It had been stated by the Author that he meant "the actual power developed compared with the power theoretically possible under the given conditions of initial pressure and expansion." The ratio of expansion was not fixed by the conditions, as the available range of temperature was, but was within the discretion of the engine-designer; it was one of those points which the standard had to try. If the standard was adjusted to suit the conditions, by varying the assumed ratio of expansion, Mr. Robinson.

Mr. Robinson. it might not be a standard at all. A certain weight of steam had to be utilized between a certain admission temperature (or pressure) and a certain condenser temperature (or pressure); the true standard for comparison was the largest diagram that could be obtained by expanding that weight of steam between those limits of temperature, of course in a cylinder assumed to be non-conducting. To shorten the standard diagram merely because an engine had been designed with too small a ratio of expansion was surely incorrect. He admitted that the Author had precedents in his favour; Prof. Osborne Reynolds, in a Paper on Triple-expansion Engines and Engine Trials,[1] had similarly shortened his standard diagram; but the late Mr. Willans had pointed out that "if the standard of perfection were to be altered to suit the point of cut-off which happened to be employed in any engine under test, the meaning of the term 'efficiency' would be lost, because the results would probably show a donkey-pump or a steam fire-engine carrying its steam throughout the stroke to be the most 'efficient' engine in existence—the losses from initial condensation being so small that the diagram to be expected from each pound of steam would be obtained almost in its entirety."[2] To cut off the toe of the possible diagram merely because the actual one to be tested had been so shortened—it might be for no better reason than to save the first cost of sufficiently large cylinders—seemed to him to be totally wrong.

Objections of less importance might be taken, first, to the standard diagram being carried down to zero back-pressure; secondly, to expansion being assumed to follow the saturation curve. It had been considered by Mr. Willans that the cost of removing back-pressure below that corresponding to about 110° F. exceeded the possible gain, and he therefore treated 110° as a theoretical condenser temperature, or as the lower limit to which expansion ought theoretically to be carried. Such a limit had not, however, been fixed by nature, and agreement could hardly be expected upon it. It was also difficult, no doubt, to fix an ideal expansion line of general acceptation, but he shared Mr. Willans' inability to see why the saturation curve should be chosen. It was a curve which could not possibly be conformed to in the expansion of the total quantity of steam supplied to the engine under any circumstances; for even if the steam in the cylinder, by means of heat supplied to it from the jacket, were kept in

[1] Minutes of Proceedings Inst. C.E., vol. xcix. p. 152.

[2] *Ibid*, vol. cxiv. p. 53.

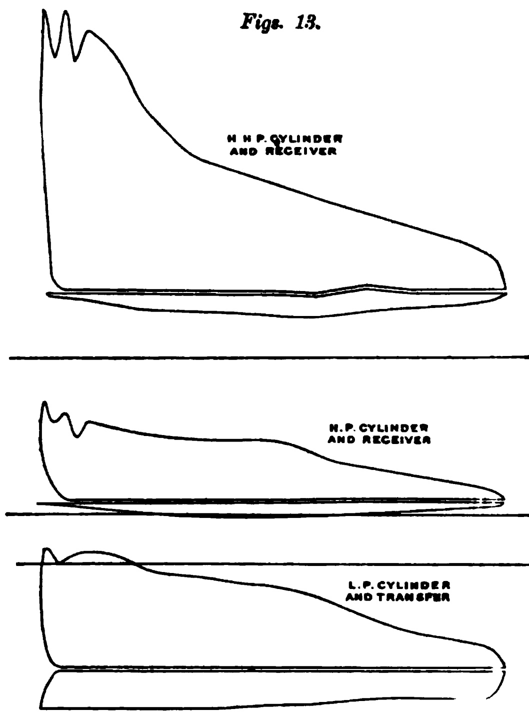
a dry saturated state, it must be at the expense of condensation in the jacket: the steam as a whole, including both that in the cylinder and that in the jacket, could not possibly remain in the dry saturated state. To represent the whole volume of steam as expanding in that condition was to imply that the standard was not the available heat contained in the steam actually supplied, but that heat together with some other heat. The adiabatic curve was surely the rightful standard, for whereas on the one hand it rightly made no allowance for losses from condensation, re-evaporation, radiation, and imperfect expansion (seeing that all these were points which the standard was appointed to try, being all more or less capable of improvement); yet on the other hand it gave credit for liquefaction due to the conversion of heat into work—a change which was the end and object of the engine's existence.[1] Mr. Robinson.

These objections to the lower limit of temperature and to the expansion curve were but of secondary importance; it was not needful to criticise too closely the exact construction of a diagram intended only to act as a rough standard, if it was to be alike for all. But cutting off the toe—that was, arbitrarily limiting the range of expansion to a different extent in each case—was another matter. It struck at the meaning and principle of a standard of excellence, for, by the Author's plan, different engines, though working under the same temperature-conditions, were no longer compared by the same standard. In one matter he cordially agreed with the Author, viz., in praising the Cornish engine, though he would like to know how far the authority for a consumption of 19 lbs. per I.HP. in 1844 was really trustworthy, and whether it was more than a deduction from bushels of coal consumed in the furnace. But the Author did not need to speak of the Cornish engine as wholly superseded by the modern compound or triple-expansion engines, for perhaps the smallest steam consumption yet recorded, all things considered, was in a recent trial with a Cornish engine, a triple-expansion Cornish engine—for that was the true description of a Willans single-acting triple-expansion engine, unlike as it was, superficially, to the pumping-engine of James Watt. A set of diagrams from this engine was

[1] Such liquefaction must arise during the conversion of heat into work if it be assumed that the cylinder of non-conducting material is supplied with saturated steam. A steam-engine working with superheated steam must naturally be compared with a different standard, namely, the standard diagram already discussed, with an added area representing the superheat. If the efficiency comparison were made directly in heat-units, upon the $\theta\,\phi$ diagram, according to Captain Sankey's method, instead of upon a $p\,v$ diagram, superheating would necessarily be taken into account.—M. R.

Mr. Robinson. given in *Figs. 13*. It would be seen that each cylinder had with it a diagram from the under-side of the piston—a true Cornish diagram, save that, as the lower end of each upper cylinder exhausted into another larger cylinder instead of into a condenser at constant pressure, the bottom line of its diagram was not straight; these were what were commonly called "receiver diagrams." The corresponding diagram below the low-pressure piston was a true Cornish diagram—called by the makers the "transfer" diagram. In the Cornish engine James Watt had in fact produced the most

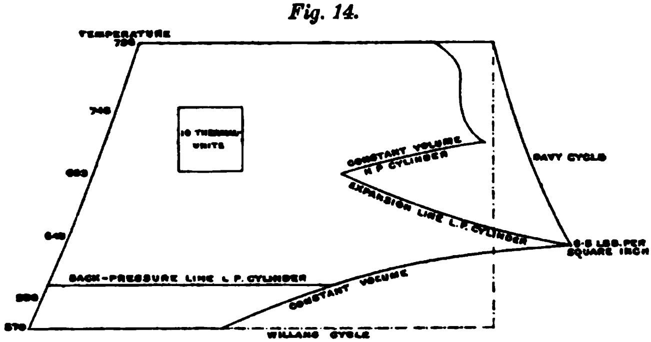
Figs. 13.



perfect engine of which the pressures of his day admitted. His other, or double-acting engine, being necessarily a pure simple engine (whereas the Cornish might be called semi-compound), was naturally inferior, and it was singular that the line of improvement since that time, in utilizing the higher pressures available, had almost exclusively followed the worse rather than the better engine. In reverting to single action, Mr. Willans reverted also to Watt's best engine; and the remarkable economy his engines attained to, under circumstances of high speed and small size,

generally supposed to be inimical to low steam-consumption, was but the natural consequence of following the great master closely. The engine just referred to, which drove a flax-mill in Belfast, had been tested for the owners most carefully and completely by Mr. A. Basil Wilson, after some five or six months' regular running. The consumption of steam per I.HP. per hour was 12·49 lbs.; and as the I.HP. of the three complete lines of parts of which the engine consisted was 399 (the engine was capable of indicating 500 HP.), it would be observed that that remarkable economy was really that of an engine indicating one-third as much, or only 133 HP. The steam-pressure was 170 lbs. per square inch in the engine; the revolutions 300 per minute. He thought these facts entirely bore out the Author's good opinion of the Cornish cycle, and should encourage him not merely to praise it in regard to past history, or as a pumping- Mr. Robinson.

Fig. 14.



engine cycle merely, but to advocate its use under modern conditions.

Mr. H. F. W. Burstall thought the defect in the Author's cycle—of cutting off the toe of the diagram—could be even more strongly urged than had been done by Mr. Robinson. It was unjust to an engine which employed a high ratio of expansion; and he thought the entropy diagram, or, as Mr. MacFarlane Gray preferred to call it, the θ ϕ diagram, *Fig. 14*, would illustrate that better than anything else. In the Willans cycle the steam started as water at 570° F., becoming heated until it reached a temperature of 793°, which corresponded to a pressure of 110 lbs. per square inch. When it reached the dotted line, the whole of the water had been converted into steam. From that point the adiabatic expansion was shown, until the temperature had fallen to its initial point of 570° F. It then followed the horizontal line until it reached its Mr. Burstall.

Mr. Burstall. initial stage of water. From the Author's cycle in the same *Fig.*, it would be seen that the two were coincident until a pressure of 110 lbs. per square inch was reached on the steam line. They then followed the thick black curved lines down to a pressure of 6·5 lbs. per square inch, proceeding along the fine line, until the temperature again became 570° F. The difference between the two cycles was shown by the large area under the fine line, and he had measured the efficiencies of the two cycles. Taking first the Willans cycle for the engine No. 4, a pumping-engine at the Addington Waterworks, the thermal efficiency with the Willans cycle was 55·4 per cent.; the heat lost in the high-pressure cylinder was 4·68 per cent.; that lost between the two cylinders was 3·58 per cent.; in the low-pressure cylinder 5·89 per cent.; during exhaust at constant volume 16·99 per cent.; and back-pressure consumed 13·46 per cent. In addition to that he had worked out with the Author's cycle an efficiency of 65·9 per cent.; the heat lost in the high-pressure cylinder was 6·22 per cent.; between the cylinders it was 4·78 per cent.; in the low-pressure cylinder 10·54 per cent.; and the loss from back-pressure was 12·6 per cent. It would be observed that he had given no clearance loss. It had been taken into account in drawing the saturation curves on the pressure-volume diagrams, and hence such loss would appear partly in the cylinder loss and partly in the back-pressure. The greatest difference between the two cycles would be noticed in the large amount of heat lost during the exhaust at constant volume, nearly 12 per cent. of the total heat of the steam. That showed more clearly than anything else what an exceedingly good cycle Mr. Willans had chosen when working out his standard engine trials. It also gave a good indication of what should be looked for in the diagram of an engine.

Mr. Raworth. Mr. J. S. Raworth regretted he could not agree with the conclusions drawn in the Paper. He proposed to examine whether the results given at the close of the Paper followed from the arguments employed in it. The title of the Paper was "Steam-Engine Economy," but on the first page the term "efficiency" was used, which was later on developed into "engine-efficiency." He thought the proper title of the Paper perhaps should have been, the "Davey curve of efficiency," because, as described in the Paper, it was not a proper definition of any engine-efficiency as it existed. He would refer to the second paragraph, in which the Author said, "As early as 1844 the Cornish engine was, for the steam-pressure then practicable, a more efficient engine than any other that has been produced subsequently. By the

term 'efficiency' the Author means the actual power developed compared with the power theoretically possible under the given conditions of initial pressure and expansion." He presumed that meant expansion within the limits of a given cylinder. It had further been stated by the Author, "Some Cornish engines at that time produced one I.HP. per hour for a consumption of 19 lbs. of steam at a boiler-pressure of 30 lbs. per square inch. Their efficiency was thus greater than that of modern triple-expansion engines giving one I.HP. per hour with 13 lbs. of steam at a pressure of 120 lbs. per square inch in the boiler." It could not be appreciated readily that because an engine in 1844 took 19 lbs. of steam per I.HP. at a pressure of 30 lbs. per square inch it was more efficient than one which in the present day took 13 lbs. of steam at 120 lbs. pressure; because in the one case the number of British thermal units per HP. was about 21,000, and in the other about 14,000. Step by step the Author had proceeded to show that the Cornish cycle had great advantages over other cycles, and had finally come to the conclusion, "It has been shown that the compound Cornish cycle engine is superior to the others, in suffering a smaller loss from initial condensation, and it might be made to effect a saving of 6 per cent. of steam by heating the feed-water to a higher temperature than that possible with other engines." It was learnt by degrees that the Author was of opinion that engine-efficiency as defined meant also economy, and he presumed that was the central idea of the Paper. With one statement some engineers would no doubt agree—"Any addition of heat to the steam tends to increase economy by increasing the engine-efficiency. The engine-efficiency generally increases with the average pressure, and the economy increases with the ratio of expansion and with the average pressure." Taking that definition of engine-efficiency, the result was arrived at that if a diagram were constructed showing a cut-off at three-fourths of the stroke almost the highest possible efficiency was obtained. That was the direct outcome of the Davey diagram. If it were called by the name of the "engine-efficiency diagram," it would carry with it the dangerous probability, on the assumption that the efficiency of an engine could be measured by the method described, that the most expensive engine in steam would appear to have also the highest engine-efficiency. As the last step of the argument, "the Author has shown that the Cornish cycle possesses considerable economical effect. It is supposed that initial condensation increases with the surface of the cylinder-walls and the fall in temperature to which they are exposed. Mr. Raworth.

Mr. Raworth. On that assumption, a comparison can be instituted between the values of initial condensation in different types of engines without the actual values being known." He thought that meant that although it might be difficult to ascertain the actual amount of condensation in a cylinder, yet if the fall in temperature be multiplied by the area of the cylinder exposed to those differences of temperature, figures would be obtained which would be oftentimes an advantage. The results were as follows:—"Compound Cornish cycle, 1; triple-expansion, 1·34," the assumption being that the triple-expansion engine in this respect was 34 per cent. worse than the Cornish engine. Turning to the diagram of the Cornish cycle and to the Table of losses, it was found that the loss A was 15·2 per cent. In *Fig. 5*, showing the triple-expansion curve, in which the product of the surfaces and the fall in temperature was 34 per cent. worse than the other, the loss A was only 14·9 per cent., so that the apparently worse engine from that method of computation was shown to be actually better. That result would have been expected, although the Author apparently did not expect it, and upon that theory he had built his argument, which ended thus,—that on the assumption that certain things were going to happen, certain Tables resulted, in which the Cornish cycle appeared as 1 and the triple-expansion engine as 1·34 with regard to cylinder-losses. The assumption arrived at as to the probable advantage to be gained by a certain cycle from the diagrams given by the Author did not appear to be borne out. From that point the Author proceeded at once to the conclusion—with the interjection only of a certain appliance yet to be invented, whereby a further economy was to be effected—"The Cornish cycle might be made to give increased economy by a method which appears to have hitherto escaped notice. The steam, which has done its work and has passed the equilibrium-valve, possesses considerable pressure and temperature, say a pressure of 10 lbs. per square inch and a temperature of 194° F. If a connection having a non-return valve were made to a feed-water heater from the equilibrium-pipe, as shown in *Fig. 12*, the feed-water could be heated to, say, 180° F., on its way to the boiler." He did not think the Author was quite correct in that. In his own experience he had seen many appliances for heating the feed-water, but all were surrounded with difficulties which up to the present time had not been overcome. One difficulty, as shown in the diagram, was that the feed-water heater would gradually become filled with air, and no more steam would go into it; and unless there was some mechanism

by which it could be intermittently connected with the condenser, it would be a failure. There was still an opening for an invention in that particular direction before the Author's feed-heater could be easily applied to the improvement of the Cornish engine. Finally, it was stated, "Taking all things into consideration, the Author is of opinion that this engine, combined with a feed-water heater, will be found to be between 8 per cent. and 10 per cent. more economical per actual HP. than the triple-expansion engine." He did not think that followed from the premises. There appeared to be gaps in the reasoning. From the figures given in the Paper, the Author considered that if the further invention, which he proposed to add to the Cornish cycle, could be applied, a saving from that cause of 6 per cent. of steam might be expected, and that then, with the addition of the feed-water heater, the cycle would be found to be between 8 per cent. and 10 per cent. per HP. more economical than the triple-expansion engine. Thus, without the feed-water heater, the saving to be effected by the Cornish cycle was only between 2 per cent. and 4 per cent.; and in order to realise that the engine must be made single-acting and of very much greater size than the existing engines; further, they would have to abandon all the advantages derived from a turning-moment all the way round the circle. He was sorry to have criticised the Paper unfavourably. He knew the Author had a much larger experience in steam-engines than himself, and he could only hope when the matter was explained, it would be shown that there had been some clerical errors or some misunderstanding which had led him to adopt and express a view altogether opposed to the argument set forth in the Paper. Mr. Raworth.

Mr. MICHAEL LONGRIDGE considered the proper standard of comparison was an adiabatic curve which should be continued to a particular point, and not, as the Author had drawn the curve, merely to the toe of any diagram to which the standard of comparison might be applied. In *Fig. 15* [1] A B represented the volume of the steam used Mr. Longridge.

[1] In order to render this standard diagram available for general use its value in foot-lbs., as well as the method of setting out the adiabatic from the saturation curve, is as shown below:—

Let T_1 T_2 T be the absolute temperatures of the steam at B C and any othe point E;

p_1 p_2 p the absolute pressures at B_1 C_1 E_1 in lbs. per square inch;

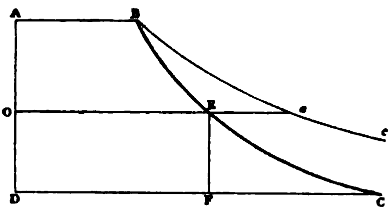
N the number of lbs. of steam used per stroke;

V the displacement of the piston per stroke in cubic feet;

U_1 the work due from N lbs. of steam expanded to the point c, or the area of the diagram A B c D in foot-lbs.;

Longridge. per stroke at the highest pressure available; B C the adiabatic for this steam; and C D the exhaust at the pressure corresponding with the temperature of the condenser. The area of the diagram represented the maximum work that could be obtained from the steam under the given conditions of pressure. If the value of any particular engine were estimated merely by the amount of the available heat it converted into work, this area would be the proper criterion to be applied. The engineer, however, wanted to

Fig 15.



utilise as much of the work as possible outside the engine. If an engine absorbed the whole of the power it developed in driving itself, it might be a very perfect thermodynamic machine, but it would be a useless motor. Every engine absorbed a certain amount of power, and in establishing a standard of comparison for a steam-engine regarded as a motor this fact should be considered. The mean effective pressure required to drive the engine being represented by E F, it would evidently be useless to continue the expansion beyond the point E in the *Fig.* This point, therefore, was that to which the adiabatic should be continued, and the curve A B E F D was the proper

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U_2 the work due from N lbs. of steam expanded to any point E, and exhausting into a condenser at temperature T_2, or the area of the diagram A B E F D in foot-lbs.;

then, using common logarithms,

$$U_1 = 772 \times N\left\{(1438 - 0{\cdot}7\,T_1)\,\frac{T_1 - T_2}{T_2} + T_1 - T_2 - 2{\cdot}3\,T_2 \log \frac{T_1}{T_2}\right\}$$

$$U_2 = 772 \times N\left\{(1438 - 0{\cdot}7\,T_1)\,\frac{T_1 - T}{T} \times T_1 - T - 2{\cdot}3\,T \log \frac{T_1}{T}\right\} + V\,N\,(p_1 - p_2) \times 144.$$

Further, if B *e c* be the saturation-curve of N lbs. of steam, B E C the adiabatic, then, drawing a horizontal line through *e* E where the absolute temperature is T, and producing it to meet A D in O,

$$\frac{O\,E}{O\,e} = \frac{T_1}{T} \times \frac{1438 - 0{\cdot}7\,T}{1438 - 0{\cdot}7\,T_1 + 2{\cdot}3\,T_1 \log \frac{T_1}{T}}.$$

In all ordinary cases the adiabatic B E is given very nearly by the equation—

$$\frac{p_1}{p} = \left(\frac{V}{V_1}\right)^{1{\cdot}135}.$$

standard of comparison. The numerical values which should be given to the condenser-pressure and to the pressure E F were subjects for discussion. Mr. Willans had taken as a standard of comparison the condenser-pressure as that corresponding to a temperature of 110°. Where the water-supply did not permit so low a temperature, the lowest possible should be substituted. As to the value of E F but little was known, but he thought that for factory engines, having heavy fly-wheels or rope-drums, about 3 lbs. per square inch on the low-pressure piston would be a fair allowance. Taking these figures, the expansion-curve on the standard diagram for a condensing engine would end when the pressure had fallen to 4·26 lbs. per square inch. Mr. Longridge.

Perhaps the practical bearing of the distinction he had drawn between the thermodynamic machine and the motor would be better appreciated by considering an example. He had recently tested two sets of mill engines, both supplied with steam at 90 lbs. per square inch. One pair had two cylinders and developed about 400 I.HP., with a consumption of 15 lbs. of steam per I.HP. per hour. The other pair had four cylinders and developed about 700 I.HP., with a consumption of $16\frac{1}{2}$ lbs. of steam per I.HP. per hour. In the first case the mean effective pressure referred to the low-pressure cylinder was $15\frac{3}{4}$ lbs. per square inch, and in the second case 24 lbs. per square inch, so that clearly the first pair were better thermodynamic machines than the second. But if from the mean effective pressures were deducted the 3 lbs. per square inch assumed to be required to drive the engines, as a motor the second pair of engines was shown to be as good as the first; for in the first case the steam used per brake HP. would be $15 \times \frac{15 \cdot 75}{12 \cdot 75} = 18 \cdot 6$ lbs., and in the second $16 \cdot 5 \times \frac{24}{21} = 18 \cdot 8$ lbs. The importance was thus shown of fixing a limit to the extent to which expansion could be usefully carried apart from the question of cylinder-condensation. He was afraid many of the engine trials now made partook of the nature of ploughing the sand and were as barren of results. But little labour was involved in giving the consumption of steam per I.HP. per hour and a sample diagram; though to be of any scientific value a mean diagram, with the pressures printed on it so that it might be reproduced with certainty, was essential, and the clearance surfaces and volumes, upon which the initial condensation so much depended, were equally necessary. But if even all this information were given, and time and trouble expended in investigating the action of the cylinder-walls and in calculating

Mr. Longridge. the amounts of the various losses which caused the actual diagram to fall short of the standard described, he feared that isolated trials would have little scientific value. Progressive trials, like those associated with Mr. Willans' name, would be of more use, but even these fell short of the necessities of the case. There were two points to which attention should be devoted, namely, engine-friction and initial condensation, and he feared neither investigation would be assisted by determining the "steam used per I.HP. per hour."

With regard to initial condensation, he was strongly of opinion that a method of investigation entirely different from an engine trial was needed. Initial condensation was the combined result of many variable causes, and the extent to which it depended on each separately could not be ascertained by taking the net result of all. The variation due to each such cause, as initial pressure, range of pressure, periodic time, and amount of surface exposed per pound of steam, would have to be investigated separately and its law determined. Then only could the balance of advantage be determined that would enable an engine to be constructed which would condense the minimum amount of steam. He ventured to hope the Author would at a future time present another Paper to the Institution dealing with the results of such a series of experiments, and to prophesy, if that were done, that this country would be placed, as regards this question, as much in the forefront of scientific progress as Hirn had placed Alsace forty years ago.

Dr. Kennedy. Dr. A. B. W. Kennedy said some twenty-five years ago, when compound engines had first been started on the Tyne, and he was a draughtsman in Palmer's Shipbuilding and Iron Co., it was his duty to work out the original calculations for those engines, and he then used in connection a diagram much like *Fig. 4* in the Paper. He had certainly found it extremely useful; but from some of the remarks made in the course of the discussion, it appeared he had been committing something hardly short of a crime in having ventured to take such a step. He was not however ashamed of what he had done, for he knew from experience that the proposed comparison of diagram-areas was exceedingly useful. But he not only omitted to use the adiabatic curve and to carry the curve on to the somewhat uncertain one and only point which should be used, but he had actually used a hyperbola to represent the expansion curve; and he confessed that if he were doing it again he should again use the hyperbola. He would certainly never use an adiabatic curve or a saturation curve in a case where the com-

parison was simply one of areas, and not of quantities of heat. Dr. Kennedy. The matter had no doubt been pressed very much further than it was capable of being pressed, and the Author had made one cardinal mistake in judgment in calling the ratio "efficiency." If he had only called it "efficance," or "efficacity," or "self-effication," or "load-factor," his severest critics would have lost one of their most effective weapons. It had been said that if this matter were pushed to an extreme a donkey-engine would appear to be the most "efficient" engine. Surely there was nothing so preposterous in this. In a certain sense it might be the most efficient engine, as long as efficiency was defined exactly. The word had already been used in so many different senses, that it sounded somewhat pedantic to object on scientific principles to its being used in one other. Of course it was primarily necessary not to confuse the terms "efficiency" and "economy," or to use either word in such a sense as to mislead. As long however as the word "efficiency" in the Paper was taken to mean exactly what it was there said to mean, it would be found that a comparison of diagram-areas was quite useful; and he thought, further, that the Author, for certain purposes, was quite justified in comparing areas for each engine as it stood. Of course, if anyone proceeded to generalise from these limited data, a mistake would be made; but by that particular method of investigation it was possible to arrive at certain useful results which would show that in certain important points losses in connection with compound engines were really made, which did not occur in connection with single-cylinder engines. This was doubtless unimportant to those who knew it all before, but some did not do so, and had to draw it out for themselves. He certainly had not known it personally until he had drawn it out and so discovered it. He therefore did not agree with the severe censures that had been passed on the Author for that part of his work. The Paper raised the interesting question of the use of live steam for heating feed, a matter which had been a great deal discussed in connection with marine engines, and which he believed had been discussed theoretically by Prof. Cotterill, and had been shown to be advantageous under certain circumstances. The matter was a very interesting one, and was not quite so easy to work out as some speakers seemed to have assumed. An expression that had been used by Mr. Robinson might be misinterpreted, as covering the statement that liquefaction was the end and object of an engine's existence. He had often seen statements of that kind made, and desired to protest most strongly. If superheated steam was used, the con-

Dr. Kennedy. version of heat into work was not accompanied by liquefaction; if air was used, it was not; if a mixture of half steam and half water by weight was used, it also was not; if either was doing work, there would be evaporation, not liquefaction. It was a matter on which there was a certain amount of misunderstanding, and he much disliked the way it was often put, for he did not think it at all expressed the scientific truth of the matter. Liquefaction was a most unfortunate concomitant of certain working conditions in certain steam-engines, but it depended solely on the physical constants of the vapour employed, and was in no sort of way specially connected with the performance of work. There was no relation of equality between the heat given up in liquefaction and the work which happened to be done at the same time. The statement of the necessity for liquefaction accompanying the performance of work was no more a true generalisation than was the Author's method of making a comparison, if used as a criterion of merit, of a number of engines of different types.

Mr. Wingfield. Mr. C. Humphrey Wingfield observed that the term "efficiency," as applied by the Author, was a measure of the power developed by an engine of given size. Compared by that method, of two engines of equal size, working pressure and ratio of expansion, the one which gave the higher power would be considered the more efficient. In referring to a high economy the Author had used the expression, "in other words what was its engine-efficiency?" (p. 13), thus almost, if not quite, identifying the two terms; and in another part of the Paper it was pointed out that high engine-efficiency, by which was meant a full diagram, was chiefly due to diminished cylinder-condensation. He could not agree with these two assumptions, for it was not unusual to find a full diagram caused by re-evaporation, during expansion, of the water condensed during admission. This condensation did not alter the position of the admission-line if the steam-pipes and passages were of sufficient area; and as the cylinder was usually as hot as the steam by the time the point of cut-off was reached, no further condensation, save what was due to work done, took place after cut-off. The back-pressure was more affected however, unless the ports were large; but he thought a full diagram was as often due to initial condensation as to its absence. Some speakers, when animadverting on the Author's use of the diagram ratio as a measure of efficiency, had overlooked the fact that an equal initial pressure and ratio of expansion had been assumed before applying the diagram ratio as a test of probable economy. Without this provision the Paper would be self-contradictory. He could not agree that the state-

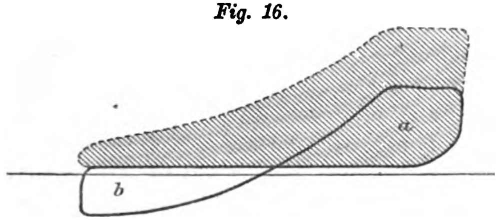
ment of the units of work developed per cwt. of coal was of scientific interest unless the quantity of steam produced at the same time was known. It did not even appear to be of much commercial value, as the same engine might require a very different quantity of coal to be burnt when used in connection with a different boiler, so that it would be impossible to give a guarantee of economy with a duplicate engine, unless the whole plant proposed was identical with that experimented on. As it was only within the last few years that accurate methods of measuring the coal used during a trial had been devised, the results of the early boiler-trials mentioned in the Paper were open to doubt. The difficulty was to ensure that the state of the fire was exactly the same at the commencement and end of the trial, and until Dr. Kennedy had taken the question in hand it had depended on the stoker's memory of the appearance of the fire—a very unsatisfactory arrangement. Mr. Wingfield

Steam of 160 lbs. per square inch pressure was spoken of by the Author as being expanded sixteen times to bring it down to 10 lbs. per square inch. That was only correct if the pressures were absolute; and he wished to know if all the pressures mentioned in the Paper were on the absolute scale. He did not understand what was meant, on pp. 9 and 10, by taking units of heat "from the heat of the steam, and not from the heat of the feed-water," or whether the temperature of the feed-water was assumed to be equal to that of the steam. It was also assumed (p. 10) that 5 per cent. difference of back-pressure would produce 5 per cent. difference in the economy. This was equivalent to stating that if C, in *Fig. 3*, varied 5 per cent., the area of the diagram would vary 5 per cent. also. In suggesting a feed-heater in connection with the equilibrium-pipe of a Cornish engine he thought the Author had overlooked the increased initial condensation which would result from robbing the steam—at present usefully employed in warming the cylinder—of part of its heat. The Author's plan of dividing up the unfilled space of the theoretical indicator-diagram was likely to prove of service in locating defects, but the space B was not always without value. A compound engine, when working non-condensing, might expand the steam below the atmospheric line, producing a low-pressure card somewhat as shown by the full lines (*Fig. 16*). If the areas *a* and *b* were equal, the low-pressure cylinder would be doing no work. Cases sometimes arose where the area *b* was larger than the area *a*, and then the difference represented so much power employed in opposing the motion of the engine. For

Mr. Wingfield. instance, a case had been described [1] where, of 186 I.HP. developed in the high-pressure cylinder, 120 I.HP. was expended in dragging the low-pressure piston "against vacuum."

In another engine by the same makers, the clearance in the high-pressure cylinder was increased till it bore the same ratio to the high-pressure cylinder volume that the latter bore to the low-pressure volume. The result was a higher pressure of release in the high-pressure cylinder, and consequently a higher initial pressure in the low-pressure cylinder. The low-pressure diagram was in this way raised entirely above the atmospheric line, as shown in the dotted line in the *Fig.*,[2] the work and range of temperature was more equally divided between the cylinders; and as the compression in the high-pressure cylinder was so arranged as to fill the clearance with steam at high temperature, the steam used per stroke was not increased, and the result was an extremely economical engine. In

Fig. 16.



Tables I and II, Appendix I, although the ratio of expansion and initial pressures agreed to two decimal places, the values of $\frac{p}{P}$ were widely different, so much so as to transpose the double and triple compound engines in the order of "engine-efficiency."

Mr. Halpin. Mr. Druitt Halpin remarked that, with reference to efficiency, the Author apparently gave a distinct definition of what he meant on p. 3, in saying, "The efficiency of a steam-engine may be expressed by the number of units of heat," &c. Having laid that down as a basis, he took the saturation-curve and worked from it. The ratio was a well-known one, although it was sometimes called by another name—the "ratio of diagram-areas." In that way it was intelligible, as clearly showing what losses had to be met and provided for in practice. He thought the only possible meaning the word "efficiency" could have, was the ratio between the number of heat-units presented to an engine and the

[1] *Engineering*, vol. liii. p. 57.

[2] The original card was of somewhat different shape from that shown.

indicated power, or better, the actual power developed. In speaking of the sub-division of the losses A, B, and C, the Author stated that ratio included cylinder-condensation, and that that waste also included condensation in the jacket; but he failed to see how jacket-condensation could be observed under the circumstances from the curves given. Details of the conditions producing the losses had been given by the Author, who had stated that the principal loss A was almost wholly due in the simple engine to cylinder-condensation and radiation; and further that this loss might be 5 per cent., "due to losses other than cylinder-condensation." But in many engines doing exceedingly good work that loss was much more than 5 per cent.—in fact, in extreme cases it was nearer 50 per cent., and still satisfactory work was obtained. It had been stated by the Author that economy would result from superheating the steam. That was hardly a point in dispute. As far as he knew, the highest economy attained at the present day had been obtained by that means. Several parts of the Paper were difficult to follow, because the Author had not expressed clearly whether total pressures or gauge pressures were referred to. Mr. Halpin.

Mr. H. DAVEY in reply said absolute pressures were used throughout the Paper. He drew the greatest possible distinction between "efficiency" and "economy." By "efficiency" he meant efficiency for a given ratio of expansion; and by "economy" absolute consumption of feed-water. By "initial pressure" and "expansion" were indicated the initial pressure and the ratio of expansion then employed. He had been criticised severely on theoretical grounds, but really he took up no theoretical position, having endeavoured to deal practically with the steam-engine diagram; and as it was necessary for purposes of comparison to have some standard, the saturation-curve appeared to be a convenient one. He might have taken the hyperbola, which would have been more readily constructed; but the saturation-curve was not difficult to lay down, for it had the practical advantage, if it was desired to ascertain dryness fractions, of affording a curve to which some points of the engine-diagram could be referred. In order to arrive at absolute results, it would have been necessary to adopt some standard of efficiency which would be unquestionable; he knew of no such standard, and it was not his object to make a theoretical investigation, but to deal practically with the steam-engine diagram as it existed. The Cornish cycle was important, although it had been disregarded by some speakers. He had stated that the compound engine Mr. Davey.

Mr. Davey. and the triple-expansion engine embodied the principles of the Cornish cycle, by tending to reduce initial condensation as compared with the same amount of expansion in the single-cylinder engine. That was clearly seen on comparing the combined diagrams of the triple-expansion with either of the diagrams of the single-cylinder engine. In the high-pressure cylinder there was little loss from initial condensation; there was apparently more in the intermediate cylinder, but there was a considerable loss in the low-pressure cylinder. If the low-pressure cylinder, instead of having a large drop between the release and the condenser, were worked on the Cornish cycle, as shown in the diagram, there would not be that great fall in temperature. There would be reduced cylinder condensation. That was an important point, and he believed by omitting the intermediate cylinder, and working the low-pressure cylinder on the Cornish cycle, an engine would be obtained quite as economical as the triple-expansion engine and much simpler to construct, having fewer moving parts. That was one of the most important parts of the Paper. The standard diagram had been criticised by Mr. Burstall, who had placed against it a purely theoretical diagram. The investigation was not intended to be theoretical, but was entirely practical, with the view of arriving at the value of different modes of steam-distribution. The weighing of the coal in the trials of the Cornish boilers had been most completely carried out. In early days great interest had been taken in the exceptional duty of Cornish engines, and no doubt the experiments had been conducted as accurately as most experiments in the present day. There was nothing exceptional in a Cornish boiler evaporating 10 lbs. of water per lb. of Welsh coal—a result which should be attained by any Cornish or Lancashire boiler.

The discussion had been directed almost wholly to criticism of the use of the term "engine-efficiency," to the almost entire evasion of the main argument of the Paper. There were several standards of efficiency, of which he had selected two: 1st. Thermal efficiency, or units of work per units of heat, which more accurately expressed economy; 2nd. Carnot's function, which took into consideration the condition under which an engine was supposed to work. That might be illustrated by a simple hydraulic analogy. Suppose there were several turbines of different construction, the relative efficiencies of which it was desired to determine. If all were tested under the same head of water, their relative efficiencies might be expressed in weight of water per unit of work done (Efficiency No. 1); but if different heads

of water were employed, then clearly it would be necessary to multiply the weight of water by the fall in each case, in order to obtain correct results (Efficiency No. 2). There were considerations in favour of his standard diagram for the purpose to which it had been applied. It had been found that the expenditure in the steam-jacket, in arresting condensation, was more than balanced by the saving in the cylinder. If it were not so, no advantage would be derived from the use of the jacket. If the additional heat imparted to the working steam in the cylinder from the jacket, or by other means, was found to be sufficient to keep the steam in a dry saturated state until the point of release, the expansion-line of the indicator-card would coincide with the saturation curve, and condensation would be entirely arrested. That economy would result from such an arrangement he had no doubt, and it was quite conceivable that such conditions might occur. Mr. Davey.

He was unable to follow the argument advanced by Mr. Raworth, who appeared to have confused efficiency with economy, Cornish engine with compound Cornish cycle, and actual loss of power, "A," with percentage difference of cylinder-condensation. The use of the adiabatic curve as a standard had been advocated by Mr. Longridge, who considered that a portion of the toe should be cut off. A diagram thus shortened would be the true theoretical diagram from which to make calculations. From the consideration that 3 lbs. per square inch on the piston would drive the engine without a load, Mr. Longridge had determined what part of the toe should be cut off. A portion of the toe of Mr. Davey's diagram was cut off, at the point where the toe of the diagram was cut off by the opening of the release-valve. Assuming that the expansion was carried to, but not beyond, the range of usefulness (and that was a matter to be determined by experiment, because engines differed so much in useless resistances), then cutting off the toe of the enclosing diagram where the engine cut it off was quite legitimate. The argument used by Mr. Robinson failed because it was based on false premises. It had been said that on the mode of analysis described in the Paper a donkey-pump would show an efficiency of 100 per cent. It could only show such an efficiency on the false supposition that it worked with no initial condensation, no clearance-spaces, and no back-pressure. A donkey-pump generally gave an "efficiency" lower than an expansive engine. Its cycle was illustrated by the non-expansive part of the ordinary single-cylinder engine cycle (*Fig. 3*). Theoretical investigators had

Mr. Davey. determined that the standard of efficiency for a perfect steam-engine, having a non-conducting cylinder, was adiabatic expansion. The steam-engine cylinder was not non-conducting, but being made of cast-iron, condensation in it was an evil, whether it arose from adiabatic expansion or from other causes. It had been the endeavour of engineers since the time of Watt to minimise the evil effects of cylinder-condensation by imparting additional heat to the working steam; and it would be found that the highest economy would be secured by altogether preventing cylinder-condensation: that could only be effected by adopting some method by which the steam might be kept dry and the curve of the indicator-diagram kept above the adiabatic line. Whether the absolute consumption of steam per I.HP. could be by that means reduced below what had been determined as the quantity per I.HP. for a non-conducting cylinder and adiabatic expansion was not a question that need be discussed. He had used the "ratio units of work per unit of heat" as a standard of efficiency in Table I. If the analogy might be allowed, he scarcely thought Mr. Halpin would be content to accept the efficiency of a turbine in terms of units of work per gallon of water consumed. The height of the fall would also be required, to show whether the efficiency was constant for all falls or was altered by variation in the mode of delivery.

Correspondence.

Prof. Dwelshauvers-Dery. Professor V. Dwelshauvers-Dery considered the Paper to be eminently practical and useful, but ventured to criticise it upon one point. Actual diagrams had been collected by the Author and compared with an ideal diagram which he had formulated and called "theoretical." The name was open to criticism, for there was no theoretical diagram except that of Carnot, than which the curve proposed was no less impossible to realise. If the first part of the cycle, that of admission, could be nearly realised, it was not the same for the second or the third part; for in supposing the action of the metallic walls during expansion to be annulled, the expansion of the steam would be adiabatic and necessarily accompanied by condensation. An adiabatic curve should therefore replace the saturation curve during the expansion in the ideal diagrams. With respect to the supposition of zero back-pressure, it was evidently arbitrary and not theoretical. A lower value might be given than all that had been obtained in modern

Prof. Dwelshauvers-Dery.

cylinders, for example 1 lb. per square inch, but not zero. With that back-pressure and the adiabatic curve during expansion, an ideal diagram would be obtained, capable of serving for the comparison of real engines, and similar to that which he had proposed in the "Étude expérimentale calorimétrique de la machine à vapeur."[1] The surface would be smaller than that of the Author's diagram, and the results would therefore be greater than those given in the Tables.

It would have been interesting to have applied the method to the case of the Schmidt engine, which had been tested by Professor Schroeter, of Munich, and in the trial on the 30th July, 1894, consumed only 10 lbs. (4·55 kilograms) of steam per I.HP. per hour. The steam had been highly superheated, the total heat per kilogram being thus augmented by 76 calories. For estimating the consumption of an engine in pounds of steam, it should be said once for all what was the number of calories to be represented by one kilogram of steam; for it was the heat-units and not the steam that the engine consumed. If it were admitted that the unit "pound of steam" represented the number of thermal units, called "total heat," of the unit pound of saturated steam at six atmospheres, in French measure 655 calories, the consumption of 4·55 kilograms of superheated steam amounted to 5·136 kilograms of saturated steam at six atmospheres, and was not less than that of the engine tested by Professor R. H. Thurston (No. 16, Table III, Appendix).

Prof. Jamieson.

Professor Andrew Jamieson thought the value to which the Author had applied the term "efficiency" would be better expressed by "steam-efficiency" or "cylinder-efficiency." As an instance of a highly efficient use of steam, he would mention the Field combined steam and hot-air engine, in which there was a hot-air pipe connection to the jacket and to each end of a single-cylinder non-condensing engine. A Root blower driven by the engine extracted fresh cold air from the engine-room, and forced it through a series of heating-pipes placed in the main flue, between the boiler or boilers and the chimney. This heater therefore occupied a position similar to that of a Green Economiser. In tests which he had made on such an engine early in 1895, the hot air had been maintained at a pressure of 1¾ lb. per square inch and delivered to the ends of the cylinder at a mean temperature of 553° F. This hot air had been admitted into the cylinder through special cylinder-covers, each containing five

[1] Encyclopédie scientifique des Aides-Mémoire. Paris: Gauthier-Villars et Fils.

Prof. Jamieson. inlet-valves which automatically opened inwards on release of the exhaust steam. The internal surface of the cylinder was consequently heated to a temperature greatly exceeding that of the steam, and the possibility of condensation was prevented. The mean result of five hours' consecutive work with a single-cylinder non-condensing engine in this way, at less than three-quarters of full load, was a consumption of 18·6 lbs. of steam per I.HP. per

Fig. 17.

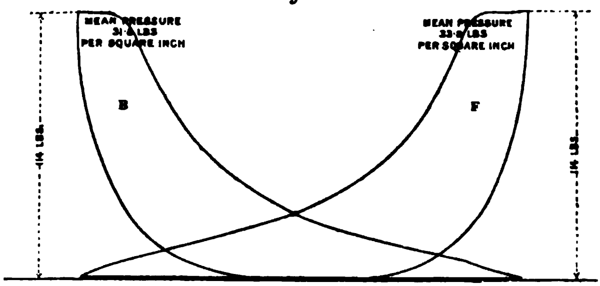
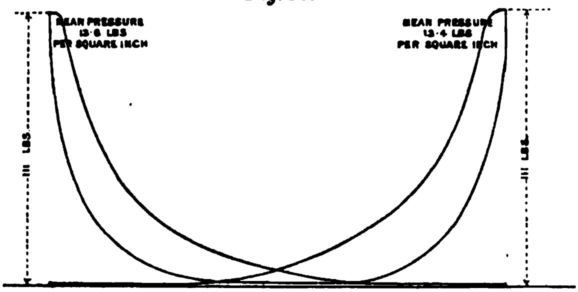


Fig. 18.

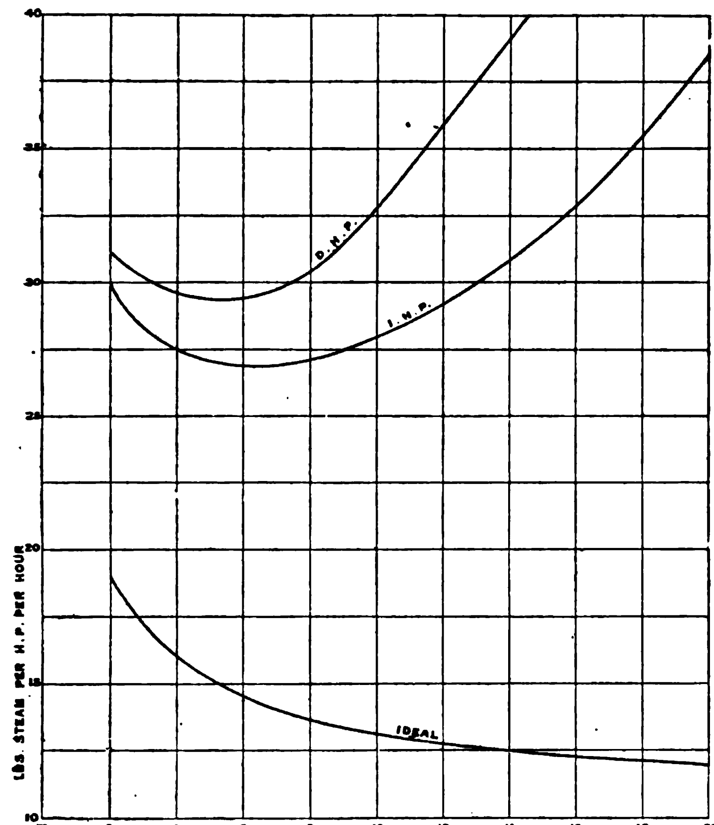


hour. Another trial, at a quarter of the full load, gave a consumption of only 21·4 lbs. of steam per I.HP. per hour. Specimens of the indicator-cards taken on these two occasions by the Wayne indicator were shown in *Figs. 17* and *18*, and formed fine specimens of expansion and compression.

Prof. Thurston. Professor R. H. Thurston remarked that the Author had condensed into a few pages much information, and many suggestions likely to prove fruitful. The curve relating the steam-consumption to the customary ratio of expansion for the class of engine considered was ingeniously derived, logically accurate, and afforded a fair basis for the deductions made in the Paper. The comparison by measurement of the three losses, A, B and C, was novel in

the form presented, and it gave an admirable method of ascertaining the relative merits of cases not otherwise easily compared. This appeared well in the case of the compound engine, referred to on p. 13, in which a reservoir was interposed between the high- and the low-pressure cylinders, in such manner, and with such proportions, as to give substantially the same effect as would sup- Prof. Thurston.

Fig. 19.



EFFICIENCIES OF STEAM-ENGINE. SMALL POWERS.

$P_1 = 75$ lbs. per square inch; $B = 4$; $d = 9''$; $l_1 = 36''$; $N = 90$.

pressing the intermediate cylinder of a triple-expansion engine. The fact that the former was operated at 175 lbs. and the latter at 125 lbs. per square inch, introduced an uncertainty which decidedly favoured the novel form of engine, giving it an apparently

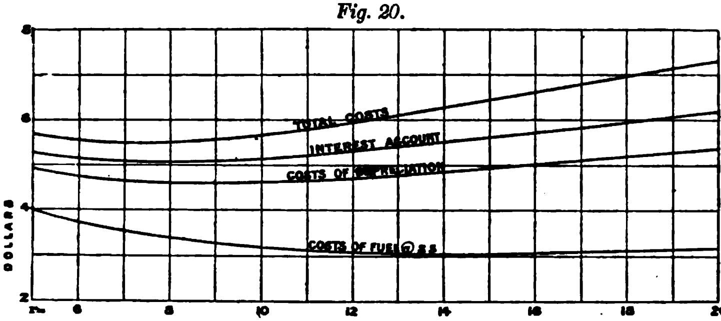
Prof. Thurston. extraordinarily high efficiency. When, however, it was considered that the proportional gain should approximate to the differences of the square roots of the pressures, the figure obtained seemed the less remarkable, and the Author's comparison showed in fact that the novelty gave a considerable defect in economy, rather than an advantage. The computations of the condensing power of the internal surfaces of the cylinder-wall in the several types of engine considered were interesting and instructive, and, to him at least, novel and surprising. He anticipated that some modernization of the Cornish system might prove helpful, but it must adapt itself to modern high piston-speeds and to rotative engines. The results deduced certainly invested the Cornish cycle engine with additional importance.

He had been accustomed, for some years past, to make such comparisons by another, and he thought original, system. *Fig. 19* exhibited the varying efficiencies of a small engine, forming one of the elements of the multiple-cylinder experimental engines now in constant use in the laboratory of the Sibley College department of experimental engineering. The lower curve showed the computed expenditure of steam for the ideal case, all wastes other than thermodynamic being extinguished. The intermediate curve showed the actual expenditure as found by trial, determining a number of points in the curve, and exhibiting, in the difference between the two lines, the losses due to thermal wastes—cylinder-condensation and radiation. When friction was taken into account, the upper line was obtained, and the influence of dynamic wastes was seen by noting the differences of the ordinates of the upper two curves, and the effect of the total of those wastes which distinguished the real from the ideal case, by comparing the ordinates of the upper and the lower curves. *Fig. 20* further illustrated the case of the engine No. 16 referred to in the Appendix to the Paper, the finance of the case being studied. The lower curve exhibited the cost of fuel in such an engine, assuming, as was often the case in America, that fuel cost about £1 per ton; the engine being proportioned on the same lines as those stated, but for varying amounts of work, by variation of the ratio of expansion. The next higher curve exhibited the cost of depreciation of such engines, measured, as before, per million gallons pumped—in this case against a head of 160 feet. The next higher and the top curve exhibited respectively the interest account and the total cost, as different ratios of expansion were adopted for the same work with engines of the same design. The method by which he had been accustomed to exhibit the relations between simple and multiple-

Prof. Thurston.

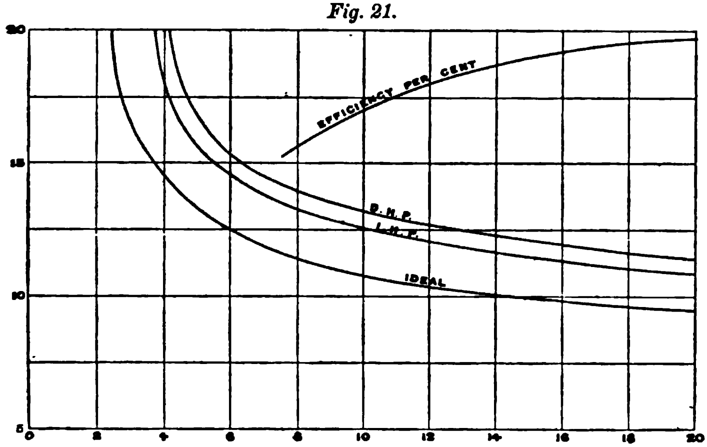
expansion engines had been described by him in a Paper[1] on "The Graphics of the Efficiencies of the Steam-Engine." A lower curve showed the ideal case, as computed by the methods of Rankine, and an upper one the total cost of the real engine when the thermal and

Fig. 20.



COST VARIATION. PUMPING-ENGINE OF HIGH EFFICIENCY. ANNUAL COST PER MILLION GALLONS 160 FEET HIGH PER ANNUM.

Fig. 21.



CONDENSING STEAM-ENGINE (JACKET-STEAM NOT INCLUDED IN REAL CASES).

$P_1 = 135$ lbs. per square inch; $P_3 = 0 \cdot 7$ lb. L.P. cylinder (triple) 74"; $l = 60$"; N = 20.

the dynamic wastes were added. The several intermediate curves exhibited the effect of adding to the computed consumption of steam for the ideal case, the dynamic, the external thermal and the internal thermal wastes of the real case. The assumption that the compound engine had about one-half, the triple about one-third, and the quadruple-expansion engine one-fourth of the internal wastes of the simple engine located the total-cost lines.

[1] Journal of the Franklin Institute, vol. cxxxviii., 1894, p. 81.

Prof. Thurston. It was interesting to observe in all these diagrams the influence, so clearly shown, of added wastes in producing a ratio of expansion of maximum efficiency,[1] having a smaller value as the wastes were greater, and also the influence of the finance of the case in the same direction. The diagram referred to, for example, might be assumed to represent one or another of the cases illustrated by it, and the added costs of maintenance and repair, of interest, taxes, and other pecuniary direct and indirect costs, which appeared somewhere, and often in large amount, in the books, measured in terms of equivalent costs of steam, as so many pounds of steam additional to those paid for at the boiler in the shape of fuel. Such added cost-lines would be superposed upon the curves of the diagram as constructed, and would evidently rise higher above these curves, as the ratio of expansion was greater; thus making the minimum total cost appear at a still lower ratio of expansion than was here obtained for the corresponding case. He had shown in past years other more elaborate methods of exhibiting the influence of cost upon the ratio of expansion of maximum financial result, but this construction was perhaps the best, simplest, and most easily laid down and utilized.

He was interested to notice that the Author had adopted a method of employing the saturated-steam curve which had been found in his laboratories exceedingly useful, as exhibiting especially the variation in the quality of steam as it passed through the engine, as well as the quality at entrance and the condensation at the point of cut-off. This construction, as applied to the experimental engine under trial in the Sibley College steam-engineering laboratory, was shown in the discussion on a Paper on "The Theory of the Steam-Jacket."[2] *Fig. 21*, exhibiting the efficiencies of a condensing engine, with steam at 135 lbs. per square inch absolute pressure, and back-pressure 0·7 lb. per square inch, related to case No. 16 in the Paper. The data obtained on its trial[3] had been employed to secure the necessary constants in the equations, and the steam demanded and efficiencies obtainable at various ratios of expansion were thus computed and the curves established. As representing probably the best work yet recorded, certainly under the disadvantage of comparatively low steam-pressures for that class of engine, it possessed peculiar interest and importance.

[1] "Manual of the Steam-Engine," R. H. Thurston, New York, 1891, part i. chap. vii.; part ii. chap. viii.

[2] Transactions, American Society of Mechanical Engineers, vol. xv. 1893–4, p. 878.

[3] "On the Maximum Contemporary Economy of the High-pressure Multiple-expansion Steam-Engine." *Ibid*, p. 313.

Jacket-steam was not included in the weight exhibited on the two upper curves for the real engine; and about 10 per cent. as a maximum at $r = 20$, should be added to their ordinates to obtain the total amount of steam supplied by the boiler passing through the cylinders and condensed in the jackets. Prof. Thurston.

Mr. DAVEY, in reply to the correspondence, remarked that the curve which he had used for his standard diagram, and called "theoretical," was not in accordance with any recognised theory, the name being only given to distinguish it from the actual indicator-diagram. The adiabatic curve was, no doubt, the true theoretical diagram for a non-conducting cylinder, but he thought it would be found that the saturation curve represented more nearly the condition of maximum efficiency in a conducting cylinder, and it was possible to conceive that such a curve could be produced by superheating the steam before admission and adding heat to it in its passage through the engine. The Paper was directed solely to the comparison of results, and it was therefore not necessary for his purpose to adopt a true theoretical diagram. He admitted that the terms suggested by Professor Jamieson were perhaps better expressions, but he had been anxious to show that one engine might give better results than another, for the same pressure and expansion, because of the differences in steam distribution; and, as that was dependent on the design of the engine, he had thought that the defects from it should be saddled on the engine. He was glad to have the support of such a high authority as Professor Thurston for the mode of treatment and the deductions made in the Paper. Mr. Davey.

He had no idea of attacking scientific methods, for which no one had a greater respect. Mathematical deductions from first principles had been of immense service in interpreting the results of experiments; but it was a curious fact that no new principle had been thus discovered capable of practical application in the economy of the steam-engine, since the days of Watt, who, without any knowledge of the theory of the latent heat of steam, had determined, by a simple experiment, the number of volumes of steam condensed by one volume of water.

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26 March, 1895.

SIR BENJAMIN BAKER, K.C.M.G., Vice-President, in the Chair.

The discussion upon the Paper on "Steam-Engine Economy" occupied the evening.

2 April, 1895.

WILLIAM HENRY PREECE, C.B., Vice-President, in the Chair.

On the recommendation of the Council, having regard to the exigencies of the building operations, it was

Moved by the Chairman, seconded by Sir Benjamin Baker, K.C.M.G., Vice-President, and

Resolved,—That after the 9th of April there be no Ordinary Meetings in the current Session, other than such as may be required for particular purposes as specified by the By-laws.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Member.

Alexander Barker Bassett.
Philip Henry Brown.
Stephen Butler Cottrell.
William Bernard Godfrey.
Richard St. George Moore.
Edward Martin Smith.

And that the following Candidates had been admitted as

Students.

John Hawksworth Armytage.
Arthur Lionel Boden.
Ernest Melville Collins.
Alfred Edward Edleston.
Wilfrid Holland.
William Henry James.
John Aloysius Kennedy.
Joseph Wood Kershaw, B.Sc.
Edward Slater McDonald.
James Neish.
Hubert Townsend Storrs.
Leonard Godfrey Pinney Thring, B.A.

The Candidates balloted for and duly elected were: as

Members.

Richard Elihu Dickinson.
Elihu Thomson.
Walsh Wrightson.

Associate Members.

John Charters Boyle, Stud. Inst. C.E.
Herbert Dale Cullen.
Frank Horace Frere, Stud. Inst. C.E.
Herbert Alfred Garratt.
Frederick Grover, Stud. Inst. C.E.
Frederick George Heaton, Stud. Inst. C.E.
Alfred Herbert Hewitt.
William Alfred Jenkin.
Joshua Lambert, Stud. Inst. C.E.

Associate Members—continued.

ALFRED PERCIVAL LIVESEY.
WILLIAM ALFRED SABINE MESSER.
GODFREY WILSON MOORE.
CHARLES HENRY OLLEY, Stud. Inst. C.E.
WILLIAM ALEXANDER PATERSON.
BRIAN ALBERT RAVES, Stud. Inst. C.E.
WILLIAM HARRY RUNDALL, Stud. Inst. C.E.
ALFRED SCRATTON.
CHARLES JOSEPH SEAMAN.
FRANCIS ERNEST WENTWORTH-SHEILDS, Stud. Inst. C.E.
HUGH WORTHINGTON STATHAM, Stud. Inst. C.E.
THOMAS WATSON.
ALFRED ERNEST YOUNG, Stud. Inst. C.E.

(Paper No. 2879.)

"Torpedo-Boat Destroyers."

By JOHN ISAAC THORNYCROFT, F.R.S., M. Inst. C.E., and SYDNEY WALKER BARNABY, M. Inst. C.E.

UNTIL the year 1885 the British Navy possessed no vessels specially designed to destroy torpedo-boats. In that year it was decided to build a number of vessels for this purpose of about the same size and speed as the torpedo-boat, but having a greatly superior gun armament. Torpedo-boats then carried, in addition to their torpedo-tubes, one or two machine-guns of the Nordenfelt or Hotchkiss pattern, firing steel shot between 1 inch and 1½ inch in diameter and between ½ lb. and 1 lb. in weight. The vessels which were to serve as catchers, Fig. 1, Plate 1, were to be armed with two 3-pounder quick-firing shell guns, and three two-barrelled Nordenfelt guns. They could fire thirty shots per minute ahead and 390 per minute on the broadside. The design provided for an alternative armament of torpedo-tubes, and when these were carried the two 3-pounder guns would be dismounted, leaving only the three Nordenfelts. Four such boats were built at Cowes, twenty-five at Poplar, and twenty-five at Chiswick. They were 125 feet long, of about 65 tons displacement, and had a guaranteed speed of 19 knots per hour. This speed was exceeded on the trials of many of them by between 1 and 2 knots. Before their completion the original intention of using them as catchers was abandoned, and they were fitted out as torpedo-boats.

In 1886, a new class of catcher, represented by the "Rattlesnake," Fig. 3, was built. These vessels were 200 feet long, 23 feet wide, of 550 tons displacement, with engines of 2,700 I.HP., giving a speed of 19 knots. They were armed with one 4-inch gun and six 3-pounder quick-firing guns besides torpedo-tubes. It was found necessary to increase the size of the next torpedo-boat catchers, as they were then called—the name has since been

changed to torpedo gun-boat—and the displacement was increased to 735 tons. Between 1888 and 1890 a considerable number of these boats was built, commencing with the "Sharpshooter." Their length is 230 feet, their beam 27 feet, and they have a draught of 8 feet 3 inches. The engines were intended to develop 4,500 I.HP., and to give a speed of 21 knots per hour, but difficulties being experienced with the locomotive-boilers, it was found impossible to obtain more than about 3,700 I.HP. and the speed did not exceed 20 knots per hour. Even this power was not developed without difficulty, and in 1892, when eleven new vessels of the type were built, the displacement was increased to 810 tons, chiefly in order to provide more accommodation for machinery. All but one have locomotive-boilers, which develop on an average 3,700 I.HP., giving a speed of 19½ knots. The "Speedy," Fig. 4, of the same class, but with Thornycroft water-tube boilers, obtained an increase of 1,000 HP. on trial; and the Authors believe that in ordinary service, since the stokers have become accustomed to the boilers, no difficulty is found in developing 5,000 I.HP. Her speed is 20½ knots per hour. In vessels of the Halcyon class, Fig. 5, now being built, the displacement is further increased to 1,070 tons, the speed being 19 knots per hour. They have no protection against shot except such as is afforded by coal-bunkers surrounding and partly covering the machinery, but their steering-gear is below water. Their armament consists of two 4·7 quick-firing guns and four 3-pounder guns, besides torpedo-tubes.

This growth in size of the torpedo gun-boat has been accompanied by greatly improved seaworthiness, and officers and men can live on board with tolerable comfort. It will be remembered that the "Gleaner" recently crossed the Bay of Biscay in a very severe gale and proved herself an excellent sea-boat. But there has been no corresponding increase of speed in the torpedo gun-boats, while the speed of the torpedo-boat has advanced rapidly.

The first torpedo-boat was built at Chiswick for the Norwegian Government in 1873, and its speed was 15 knots per hour. The next advances were made by boats built at Chiswick in 1874 and 1877, when speeds of 18·2 knots and 18·5 knots per hour were successively attained, the latter by the "Lightning," the first British torpedo-boat. In 1878, Messrs. Yarrow raised the record to 21·93 knots, in 1880 to 22·16 knots, and in 1885 to 25·1 knots per hour. In 1887, the "Ariete," which was fitted with water-tube boilers, was built at Chiswick, and she attained a speed of 26 knots per hour. In 1890, a Schichau boat is said to have reached 27·4 knots per hour, but under what conditions is not known.

There is obviously a great disparity between the speed of the modern torpedo-boat and that of the torpedo gun-boat. It is true that the advantage possessed by the torpedo-boat, although amounting to 6 or 7 knots per hour in smooth water, is considerably reduced in a rough sea, and there is no doubt that in certain conditions of weather the large gun-boats of the "Speedy" type will prove formidable foes to torpedo-boats. But the want has been felt of vessels having a speed equal to that of the fastest torpedo-boats in all weathers, and it has been supplied by the introduction of a new type known as Torpedo-boat Destroyers.

These are virtually enlarged torpedo-boats, the increase in size being determined by the conditions laid down by the Admiralty, which were that the speed was to be at least 27 knots, and that a powerful gun armament was to be carried. The result is represented by vessels of the "Daring" type, Fig. 2, Plate 1, of which forty-two are under construction. The "Daring" is 185 feet long, and has a beam of 19 feet with an extreme draught of 7 feet. The total weight of the vessel is approximately equal to the weight of the machinery of the "Halcyon" class, but her indicated horse-power is 31 per cent. greater than that of the "Halcyon." The armament consists of one 12-pounder quick-firing gun mounted on the conning-tower, and five 6-pounder quick-firing guns, four of which are on the broadside and one on the centre line aft. Figs. 6, Plate 1, show a design in which five guns can fire in the line of the keel ahead. There would be two other guns on the broadside which are not shown. A 12-pounder is mounted on the conning-tower, the smaller guns being 1-pounder Maxim guns with automatic belt-feed. It is possible that this may be too small a gun to stop a torpedo-boat, but upon this point the Authors offer no opinion, as it could only be decided by trial. It is said to be capable of penetrating 1¼ inch of iron at 600 yards, and can fire 200 rounds per minute if required. This rapidity of fire would be of great service in keeping down the fire of the enemy. It may be objected that bow guns are unfavourably placed on account of the spray which comes on board even in moderate weather when the boat is driven at high speed against a head wind. The Authors believe that a horizontal canvas screen arranged as shown in Figs. 6 would protect the men at the guns from the spray, and might prevent its coming on board altogether. The screen would be rigged out on hinged stanchions at the level of the deck, and its height above the water would enable it to be retained in position in any but very rough weather, when it could be readily stowed by turning back the stanchions supporting it.

All of the Chiswick vessels have now passed their official trials with the following results in regard to speed on three hours' trial:—

	Knots per Hour.
Boxer	29·175
Ardent	27·973
Bruizer	27·970
Decoy	27·763
Daring	27·706

Fig. 7 is a progressive speed curve of the "Daring" at about her designed displacement. Changes in the machinery after she was laid down, in order to obtain greater power and a more elaborate fitting-out of the vessel required by the Admiralty than was contemplated by the Authors when the design was prepared, caused her to be somewhat more deeply immersed when officially tried. Three runs were to have been made at each speed, but after the first and second of the last series had been completed, giving a speed of 28·2 knots and 28·6 knots per hour respectively, the air-pressure in the stoke-holds was increased and the steam was raised to the full pressure that the safety-valves would hold, so that these were blowing off during the whole of the final run. The engines responded to the higher pressure with an increase of ten revolutions per minute, and in this run, made against the direction of the tide, but in practically slack water, a speed of 29·268 knots per hour was attained, the engines developing 4,735 I.HP.

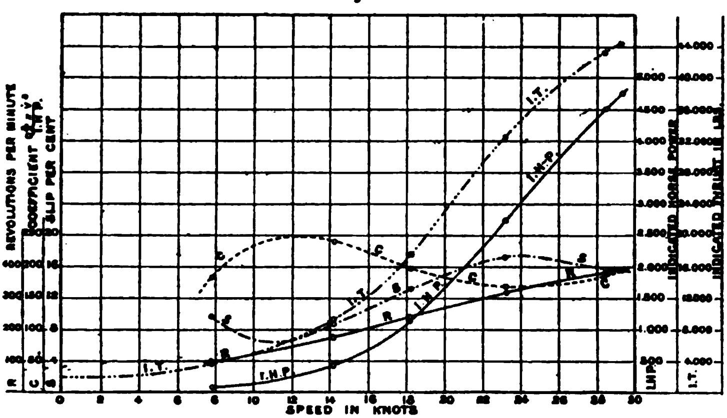
On the 8th January, 1895, the "Boxer" with her full load on board attained a speed of 29·314 knots as an average of six runs on the measured mile. As the Authors believe this to be the highest average speed hitherto attained by any vessel, it may be of interest to give particulars of these runs.

Steam-pressure.	Vacuum.	Mean revolutions per minute.	Time.	Speed.	First Mean.	Second Mean.
Lbs. per Sq. In.	Inches.		Mins. Secs.	Knots.	Knots.	Knots.
210	26¾	409	2 11·4	27·397	28·926	
210	26¾	414	1 58·2	30·456	29·312	29·119
210	27	418	2 7·8	28·169	29·442	29·377
210	26½	418	1 57·2	30·716	29·420	29·431
210	26½	416	2 8·0	28·125	29·239	29·329
210	26½	413	1 58·6	30·354		
						29·314

The mean air-pressure in the stoke-holds was $2\frac{1}{2}$ inches. During the official trial on the 25th January the mean speed of a three hours' run was 29·175 knots per hour.

The propulsive coefficient is between 0·60 and 0·63, a higher value than is generally obtained in large ships. One explanation which has been given of the apparently superior performance of small vessels, is that the indicator does not give a correct measure of the power developed by very fast-running engines, but underlogs it. As the size of the engines is increased and the rate of turning diminished an allowance has to be made for reduced propulsive efficiency. If the indicator could always be depended upon, the Admiralty coefficient $\frac{V^3 D^{\frac{2}{3}}}{I.HP.}$ should slightly increase in value in the case of similar vessels driven at corresponding speeds as the dimensions

Fig. 7.



H.M.S. "DARING"—CURVES OF HP. REVOLUTIONS, SLIP PER CENT., &c.

are increased. This is because the effect of surface-friction is less on the larger vessel. But the smaller propulsive efficiency due to the more accurate measurement of the power may cause the larger vessel to give an apparently inferior performance.

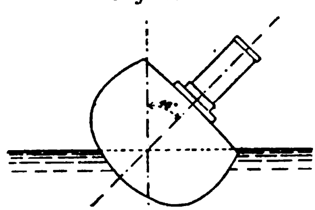
The curve of Admiralty coefficients $\frac{V^3 D^{\frac{2}{3}}}{I.HP.}$ is shown in *Fig. 7.* It is a maximum at a speed of 12 knots, and falls to its lowest value at about 24 knots per hour, the speed at which the greatest wave-making occurs. Beyond 24 knots it rises gradually, and small increments of power give a considerable increase of speed above 27 or 28 knots per hour.

The wave profile at 28 knots per hour is shown in Fig. 8, Plate 1.

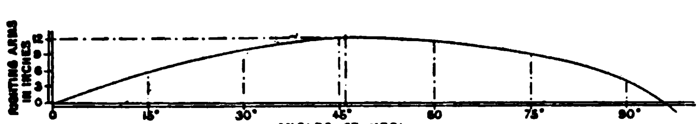
It will be noticed that there is very little squatting by the stern. The large area of the load-water plane at the after part of the vessel prevents any great change of trim at that place, and the immersion of the stern is actually less at full speed than when at rest, because the water leaves it perfectly cleanly at the abrupt corner formed by the buttock-lines.

Figs. 9 show the stability curve with all weights on board and 30 tons of coal in the bunkers. The metacentric height in this condition is 2·48 feet. The righting-moment is a maximum at 46°, and vanishes at 95°. With the bunkers empty the metacentric height is 2·58 feet, and stability vanishes at 96°. With bunkers full the metacentric height is 2·21 feet, and the vanishing angle 90°. There is a noticeable change in the conditions of stability at full

Figs. 9.



Angle of Heel for Maximum Righting-Moment.



H.M.S. "Daring"—Stability Curve.

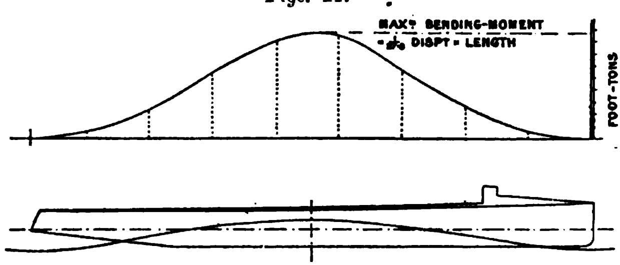
speed. The vessel appears to be more tender; and although this impression is perhaps chiefly due to the greater heeling-effect of small movements of the helm at high speed, the stability is actually reduced as compared with the normal still-water condition. The change in the water-line, which falls in the wide part of the vessel amidships and rises at the finer parts of the bow and stern, lowers the metacentre. Vessels of small initial stability and of a form which, when driven at high speed, causes the water to pile up at the bow and stern and fall considerably amidships, have been known to become unstable when so driven. The change in metacentric height due to the wave profile in Fig. 8, Plate 1, is only 2 inches, assuming that the hydrostatic pressure at each immersed section remains unchanged by the wave motion. As the effect of

the wave motion must be to increase to some extent the pressure on those sections where the immersion is reduced, and to reduce the pressure on those sections where the water is raised, the fall in metacentric height cannot be greater than that stated.

In Fig. 10, Plate 1, W W is the curve of weights. Upon a base-line proportional to the length of the vessel, ordinates are set up at intervals of 5¼ feet, representing the weight of a section of the vessel 5¼ feet long, with all its contents. A curve drawn through those ordinates encloses an area proportional to the total weight or displacement of the vessel. B B is the curve of buoyancy, ordinates at any point representing the immersed area of the corresponding section. The areas of the curves of buoyancy and weight are equal. When the curves cut one another the sections are said to be waterborne. It will be seen that for 20 feet from the bow the weight exceeds the buoyancy. The conning-tower with the 12-pounder gun upon it, the three boilers, and the engines cause the curve of weight to show above the curve of buoyancy. The pinnacle occurring in the curve at the after end of the engine-room is caused by the accumulation in the same section of the weights of four cylinders, tanks and hot-wells. The hump at the stern represents the combined weight of rudders, screws, shaft-brackets and steering-engine. From the curves W W and B B the curve of loads L L is constructed, and this curve passes below or above the line according as the weight exceeds or is in defect of the buoyancy. It of course crosses the line at waterborne sections. S S and M M, the curves of shearing-forces and bending-moments in still water, are deduced from the curve L L. The maximum shearing-forces occur at waterborne sections and the maximum bending-moments where the curve of shearing-forces crosses the line. The maximum bending-moment in still water is a hogging-moment of 236 foot-tons. The condition of loading is with all sea-going weights on board and 30 tons of coal in the bunkers. In *Fig. 11* the "Daring" is shown floating on the crest, and in *Fig. 12* in the hollow, of a wave of her own length and 9¾ feet high. In the former case a hogging-moment is produced equal to $\frac{1}{27 \cdot 8} \times W \times L$, and in the latter a sagging-moment equal to $\frac{1}{20 \cdot 3} \times W \times L$, W being the weight of the vessel in tons and L its length in feet. At the section where the greatest bending-moment occurs the stress upon the material amounts to 6·4 tons per square inch, so that there is an ample margin of strength even under such trying conditions as those illustrated. Figs. 13, Plate 1, show the two balanced side-rudders.

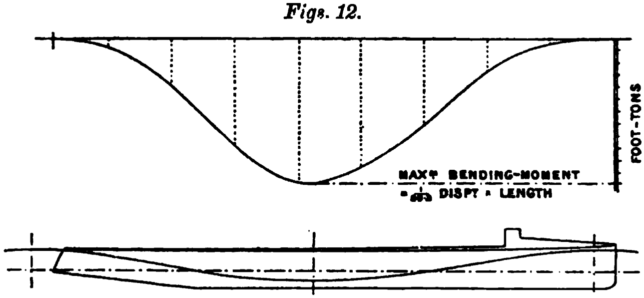
Their combined area is $\frac{1}{27 \cdot 7}$ of the area of the immersed longitudinal vertical section of the vessel. The screws revolve within 3 inches of the inner faces of the rudders, which are curved to a radius somewhat greater than that of the propellers. The rudder-heads lie in the same athwart-ship plane as the screws about which the rudders swivel. When the helm is put over, the water from the screws impinges upon them both when going ahead

Figs. 11.



H.M.S. "DARING"—CURVE OF HOGGING-MOMENTS.

Figs. 12.



Wave length, 185 feet; depth, 9·75 feet.

Scale, 64 feet to 1 inch.

H.M.S. "DARING"—CURVE OF SAGGING-MOMENTS.

and astern, and in the latter case the vessel is thoroughly under control. When the helm is amidships, portions only of the rudder-surfaces are in the screw-race, and the friction upon them is less than it would be if the same amount of total surface were disposed in the form of a single rudder at the stern. It has been found by experiment that they offer the least resistance to the progress of the vessel when they are inclined to one another at an angle of 7°, the after edges being brought together. As the water passing the inner surfaces is moving at a higher velocity than

that passing the outer surfaces, the normal pressure upon the outside is greater than the pressure upon the inside. This normal pressure has a small component in a fore-and-aft direction, due to the inclination of the rudders, which assists to propel the vessel. The propelling power of the side rudders has been proved by testing the speed of the vessel with one of them removed. The speed has always proved to be unaffected, showing that the resistance of the second rudder, which is considerable, is compensated by the forward thrust of the water upon its external surface.

The steam steering-gear is shown in the plan, Figs. 13. The rudder-heads pass through stuffing-boxes in the bottom of the vessel, and the weight is borne upon brackets secured to the deck. Toothed quadrants, attached to the lower parts of the rudder-heads, are driven by worms actuated by gear fitted to a shaft from the steering-engine. By placing one worm on the after side of the port-rudder and the other on the forward side of the starboard-rudder, nearly all the stress is taken off the engine-seating. The quadrants are either thrust asunder or drawn together according as the helm is put to starboard or port, and the thrust, instead of tending to move the shaft endwise, only puts it into compression or tension. The valves of the steering-engine are worked from the wheel forward by means of a shaft supported on roller-bearings, which makes four turns to one of the steering-wheel. Speeded up in this way, a shaft of very small diameter will transmit the necessary power. The times of turning circles were as follows:—

	Min.	Sec.
Head to Port	1	27
Stern „ „	3	30
Head to Starboard	1	29
Stern „ „	3	30

The diameters of the circles were not measured, but were estimated by the Admiralty officers at three and a half lengths when turning ahead and five lengths when turning astern. The Authors believe that the time of turning and the diameter of the circle ahead are unusually small for a vessel of such high speed and of 185 feet in length. The power of turning rapidly must be of considerable advantage to a destroyer when chasing a torpedo-boat. The extreme helm-angle is 35°. The vessel heels slightly inwards when turning at full speed, showing that the pressure upon the rudder is more than sufficient to counteract the centrifugal force tending to heel the vessel outwards. That the pressures upon the rudders are enormous at full speed may be judged from the size of the rudder-heads, which are of solid steel

7 inches in diameter. The single rudders fitted to some of the destroyers have been carried away.

The shape of the stern at the water-surface naturally suggests a fear that there would be slamming beneath it. Extended experience has, however, shown that there is no tendency to slam when under way. This is partly due to the action of the screws, and partly to the fact that the great width of the stern at the water-surface renders its vertical movement very limited. This tendency of the stern to follow the water-surface makes it possible to place the screws higher than would be prudent if the stern were of the usual form, and the draught of water is very small in the "Daring." It is less than that of most torpedo-boats, which cannot, therefore, escape pursuit by taking to shallow water.

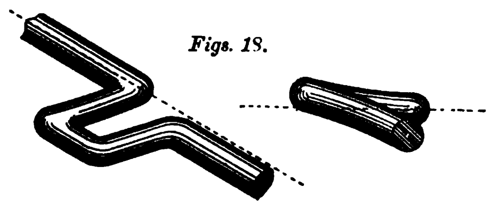
To render torpedo-boats and destroyers as nearly invisible as possible at sea, it has generally been assumed that a uniform tint is the best, and in the British Navy a dead black is preferred. If the colouring of birds which are difficult to distinguish on the sea or shore be examined, it will be found that their form is concealed by irregular patches of colour. Although the background against which they show may admit of the outline of one part being visible, other parts will match with it and will not be seen. It is possible that improvements may be made in the direction of rendering these craft less visible than at present. The destroyers have been purposely made to resemble torpedo-boats as closely as possible in order that their real character may not be immediately detected by their quarry. This can only be said to have been accomplished however in those which have no more than two funnels, as no disguise is possible when three or four funnels can be discerned.

The "Daring" has two sets of three-stage compound engines, each having four cylinders. The high-pressure cylinder is 19 inches in diameter, and the intermediate and the two low-pressure cylinders are 27 inches in diameter, with a stroke of 16 inches. At 389 revolutions, which was the mean obtained during the six runs on the official trial, the piston-speed was 1,040 feet per minute. The engines are of a novel design, and each set is divided into two parts, the high- and intermediate-pressure cylinders bolted together forming one part, and the two low-pressure cylinders similarly connected forming the other. It will be seen, Figs. 14 and 15, Plate 1, that the cylinders forming each pair are inclined in opposite directions from the vertical and partly overlap each other. The cranks in each pair are nearly opposite and have no bearing between them. By this means two adjacent cylinders

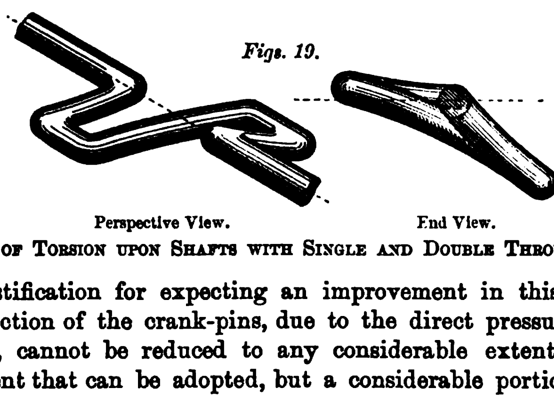
have their reciprocating parts tending to balance one another so far as vertical movements are concerned. The two low-pressure cylinders being of the same size, the balance between them is almost complete. As the cranks are not quite opposite, their weight and that of the connecting-rods require a small counterbalance weight. In the forward pair of cylinders the reciprocating weights of the intermediate cylinder are in excess, and a counterbalance weight is also required. The forward and the after pairs of cranks are in effect at right angles to each other. Figs. 17, Plate 1, show an inertia diagram prepared by Mr. Mallock which gives the amounts and positions of the balance weights required. In diagrams I and II the curves marked 1 and 2 indicate force at the axis of the shaft at the cranks and eccentrics, those marked 3 the resultant force at the axis of the shaft at each pair of cranks and eccentrics, and those marked 4 the resultant couple due to the distance between the cranks. Small black circles show the positions of the cranks and the direction of the resultants when the cranks are in the positions indicated. The revolving counterweight for resultant force is marked R.W.F.; that for the resultant couple, R.W.C.; the bob-weight for resultant force, B.W.F.; and that for the resultant couple, B.W.C. The balance-weights A and B and the bob-weights C and D are 570 lbs., 510 lbs., 215 lbs., and 216 lbs. in weight respectively. With regard to vibration in a fore-and-aft direction, there is a couple tending to rotate the shaft in a vertical longitudinal plane around a centre between any two adjacent crank-pins, but the cranks have no bearing between them, and are therefore so close together that the effect is slight. The angle between the adjacent cranks is so arranged that the pistons reach the opposite ends of the cylinders simultaneously, and the pressure upon the bearings is relieved throughout the stroke. The stress on the columns is in like manner reduced by this arrangement, and it will be seen that the columns are formed by simply prolonging the main-bearing bolts to support the cylinder, Fig. 16. The inclination of the cylinders to each other introduces a horizontal disturbing force at right angles to the shaft. The descending piston of the high-pressure cylinder, and the ascending piston of the intermediate cylinder, are moving in the same athwartship direction. Their effect is partly, but not entirely, neutralized by the movement of the slide-valves, and, as the bob-weights described by Mr. Mallock are not fitted, the rotating weights are lighter than is necessary to neutralize completely the horizontal components of the inertia forces; and consequently a horizontal vibration of the vessel is observed at certain

speeds. This disappears at full speed, and the vessel being stiff in this direction the effect is never more than slight. In *Fig. 7* is given a curve of indicated thrust calculated from the results of the progressive trial of the "Daring." The indicated thrust at zero speed, which is a measure of the initial friction of the engines, amounts to 1,750 lbs. The initial friction of the "Speedy's" engines deduced in the same way is about 2,800 lbs. Both engines were fitted with equal care, but those of the "Speedy" are of the usual three-crank type, and the Authors believe that the friction of the engines of the "Daring" is less than the lowest that can be obtained with engines of the ordinary type. They attribute this to certain features in the design, and they believe that an examination of these features will show that there

Figs. 18.



Figs. 19.



Perspective View. End View.

EFFECT OF TORSION UPON SHAFTS WITH SINGLE AND DOUBLE THROW-CRANKS.

was justification for expecting an improvement in this respect. The friction of the crank-pins, due to the direct pressure on the pistons, cannot be reduced to any considerable extent by any expedient that can be adopted, but a considerable portion of the total friction of the crank-shaft is due to the distortion which takes place in certain portions of the shaft when twisting-moment is transmitted through a crank. Two models (exhibited), *Figs. 18* and *19*, have been prepared to show the effect of this distortion upon the pressure on the bearings of the crank-shaft. *Figs. 18* represent a single-throw crank through which a twisting-moment is transmitted, and it will be seen that the crank-pin is twisted and the webs are bent.

The twisting of the crank-pin has the effect of displacing the

centre-line of parts of the shaft, and the bending of the two webs connecting the pin with the shaft causes a further displacement of the same part of the shaft in the same direction. If for the sake of simplicity it be first assumed that the bed-plate is perfectly stiff, and that the bearings fit the shaft so as not to allow of any motion other than rotary, it will easily be seen that any turning-moment acting on the shaft will tend to produce a pressure on the bearings equivalent to that moment divided by the length of the throw. As the action is repeated at every crank through which the turning-moment is transmitted, each additional crank so placed as to be subject to distortion adds to the friction of the shaft. The assumption that the crank-shaft is flexible while the bed-plate is quite stiff is not correct, but the latter is probably in all cases stiffer than the shaft, and the pressure on the bearings is believed to be more than half of that which it would be if it were perfectly rigid. In the models the shafts have purposely been made with a great amount of elasticity in order to show better the effect described. One of the bearings is disconnected from the bed-plate, and the motion imparted to it by turning the shaft is clearly seen. The direction of the motion depends upon the position of the cranks. If the bearing were quite free and the turning-moment uniform, it would describe a circle about the true centre-line of the shaft during each revolution. *Figs. 19* show a shaft in which two cranks are adjacent, and the throws equal and opposite with no bearing between them. In this case there is no appreciable tendency towards a displacement of the shaft. If the effect of the transmission of the turning-moment of the high- and intermediate-pressure cylinders through the after pair of cranks be considered in detail, it will be seen that the bending of the web of the first crank, together with the twisting of the pin, tend to move a point in the centre of the intermediate web from the true centre-line of the shaft; but the distortion of these parts in the second crank is equal in amount to that in the first, and therefore has the effect of preserving the shafting in a continuous straight line. All pressure upon the after-bearings due to distortion of the crank by the forward engines is therefore avoided.

The cylinders are unjacketed. There are a piston-valve on the high-pressure cylinder taking steam in the middle and flat valves on the other three cylinders. The exhaust takes place through the back of the flat valves, and the directness of the passage is found to have an important effect upon the vacuum obtained in the low-pressure cylinders. The indicator-cards show a much better vacuum than that usually found in the case of high-speed torpedo-boat

engines fitted with either piston-valves or with D slide-valves. The condenser is of rolled brass, with brass tubes through which water is circulated by a centrifugal pump assisted by a natural flow due to the velocity of the vessel. At all but the highest speeds this natural flow is sufficient of itself to maintain a vacuum. The air-pump is single-acting and is driven by the main engines. A Weir pump in the engine-room, drawing from a feed-tank common to both engines, returns the condensed water to the boilers. Auxiliary feed-pumps are fitted in the stokehold.

The boilers are three in number and of the Thornycroft water-tube type. The total tube-surface is 8,892 square feet. The heating-surface, which is obtained by deducting from the total surface such parts of tubes as are not exposed to heat, is 7,890 square feet. The grate-surface is 189 square feet. The boilers, Figs. 20, Plate 1, are not quite the same as those of H.M.S. "Speedy," but have been modified in order to have two furnaces in each and to obtain a greater amount of fire-grate in the available space. Three of the new "Daring" boilers are doing the work of eight in the "Speedy." 23·3 I.HP. is developed per foot of grate and 1·79 foot of heating-surface is required per I.HP.[1] The tubes are of steel and are galvanized on the outside. The products of combustion leave the fire-box through openings between the tubes at the bottom of the inner wall, pass among the tubes and escape through openings between them at the top into the central flue, through which they find their way to the up-take and funnel placed at the end of the boiler. A row of down-take tubes of large diameter connects the upper and lower vessels.

The water-level is automatically maintained at a constant height by means of a float in the upper vessel which regulates the opening of a valve in the internal feed-pipe. The float being within the boiler, none of its moving parts require to work through stuffing-boxes. It can in this manner be made more sensitive to small changes of water-level. When stuffing-boxes are employed, no movement of the float can take place until the change in its buoyancy due to a rise or fall of water is sufficient to overcome the friction of the stuffing-box. Means are provided for altering from the outside the amount by which the valve is opened for a given position of the float; so that the quantity of feed admitted at any given water-level can be adjusted to suit the rate of evaporation taking place at the time. This arrangement is shown

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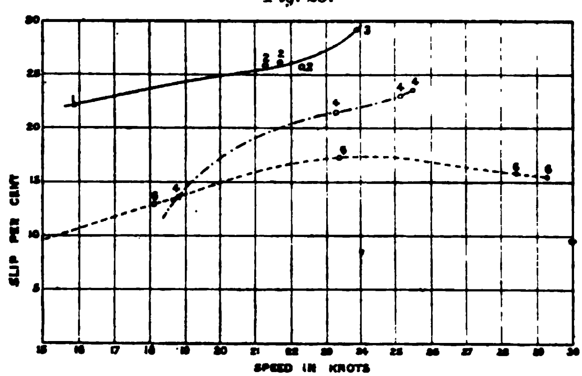
[1] The power taken is not the maximum, but the mean I.HP. developed during a three-hours' trial.

in Figs. 21 and 22. It has acted well, and its introduction has greatly improved the working of the boilers in groups. With a steady water-level automatically maintained, the stokers are able to fire with greater regularity and more steam can be made. No leakage has at any time occurred with these boilers; and since the float-gear was fitted and the feeding thereby rendered steady, no priming has been experienced. In Appendix I is given a report by Prof. D. S. Capper upon a series of tests made by him with a model of the boiler.

The total weight of the boilers with water and mountings complete including up-takes, but without funnels, is 48·5 tons. The indicated horse-power per ton of boiler is 91. The total weight of machinery and water, including spare gear, auxiliary machinery, funnels and up-takes is 115 tons, which is equivalent to 58½ lbs. per horse-power indicated by the main engines.[1]

Fig. 23.



H.M.S. "DARING"—CURVES OF SLIP PER CENT. OF PROPELLERS.

Some difficulty was at first experienced with the propellers. A series of experiments carried out by the Admiralty upon the torpedo gun-boats had resulted in these vessels being fitted with narrow-bladed screws, and the first screws of the "Daring" had the same ratio of developed area to disk area as those of the "Speedy." The blades were of elliptical form, the minor axis of the ellipse being $\frac{4}{10}$ of the major axis. As the results obtained

[1] The weights of machinery include all items included in the Tables given in the Appendix to Durston on "The Machinery of War-ships," Minutes of Proceedings Inst. C.E., vol. cxix. pp. 32–46. Air-compressors, steering and electric-light engines, oil-tanks, voice-tubes and telegraphs in engine-room, floor-plates, ladders and gratings, are classed as machinery.

were very remarkable, the Authors think it may be of interest if the screw trials are described in some detail. Three screws having the same amount of blade-surface but varying slightly in diameter and pitch gave results of a similar character. *Fig. 23* shows the curve of slip so obtained. The performances of the screws were so nearly alike that one curve only is shown for them, the points for each being marked 1, 2, 3, respectively. The slip was too great at all speeds, but at 22 knots per hour it commenced to increase very rapidly, rising to nearly 30 per cent. at 24 knots. The pitch of the screws was then somewhat reduced, and the result is shown in the slip-curve marked 4. There was a decided reduction of slip at moderate speeds, but instead of becoming less at speeds above 25 knots per hour, as was expected, it continued to increase, and at 25½ knots, which was the highest speed that could be obtained, it rose to 23·7 per cent. The Authors then arrived at the conclusion that the bad performance of the screws was due to the fact that too large a thrust was required from them per unit of area. The greater part of the acceleration of the screw race is produced by negative pressure on the forward side of the blades. If the whole thrust of the screw be divided into two parts, one part due to negative pressure on the forward side and the other to positive pressure on the after side, the negative exceeds the positive pressure in all cases except the limiting one in which no rotation is given to the race, a condition in which they become equal. The only force available for producing this acceleration in front of the screw is gravity. The recession of the helical surface as it revolves relieves the pressure of the water upon its forward face, and the water can only follow it up with the velocity which is due to the head above it. At the very small depth below the surface at which the screws work in the "Daring," a few inches only, the weight of water over them may almost be neglected and the head be taken as that due to the pressure of the atmosphere. 15 lbs. per square inch is therefore the maximum thrust which can be obtained from the acceleration produced by atmospheric pressure close to the surface of the water. If the surface is broken and air admitted, the velocity which can be imparted to the water in advance of the screw is very small indeed, being limited to that due to the head of water above it. If it be assumed that six-tenths of the whole thrust is produced in front of the propellers of the "Daring," then a negative pressure of 8½ lbs. per square inch of projected blade-surface is required by No. 4 screws at 25½ knots per hour. The thrust at the centre of the propeller is probably much less

than at portions nearer the circumference, and it may well be that at the most effective part of the blades it approaches more nearly to a state of things in which the pressure is so low that cavities are formed behind the screw-blades, filled with air and vapour boiled from the water. This view was confirmed by the very serious vibration of the stern which occurred when the engines were driven at full speed, although when the screws were removed the engines failed to shake the vessel when run at the same number of revolutions, showing that the vibration was caused by some irregular action of the propellers.

A pair of screws was made of the same diameter as No. 3 and of practically the same mean pitch, but having the blade-surface increased 45 per cent. These gave a very satisfactory performance, as shown by the slip curve marked 6, *Fig. 23*, and no further changes were made. It will be seen that the slip is the same as that of No. 4 screws at about 19 knots per hour, but at higher speeds is much less. It reaches a maximum of 17¾ per cent. at 24 knots and then falls to 15¾ per cent. at 29¼ knots per hour. Comparing these screws with No. 3, from which they differ only in blade area, it will be seen that at 24 knots per hour the slip is reduced from 30 per cent. to 17¾ per cent., and the indicated horse-power from 3,700 to 3,050. The number of revolutions per minute required to obtain 24 knots per hour with No. 3 gave 28·4 knots with No. 6. The excessive vibration also disappeared. The pitch of all the screws was variable, increasing from the leading to the following edge as is usual with Thornycroft screws. The slip is measured from the mean of the pitches of the fore and after edges at the middle of the blade. The effective pitch of the wide-bladed screws is somewhat greater than the mean thus obtained, that is, they do not turn so fast as screws of the same size but of uniform pitch equal to the nominal mean pitch. The slip curve of No. 6 exhibits a tendency to flatten at speeds above 27 knots per hour, and the Authors are of opinion that these screws would break down in the same way as did Nos. 3 and 4, if pressed to a much higher speed. Above 28 knots or 29 knots per hour greater area is required. At 29¼ knots per hour the mean negative pressure, assuming it as before to be six-tenths of the whole thrust, is 7¼ lbs. per square inch. "Cavitation," as Mr. Froude has suggested to the Authors that the phenomenon should be called, appears to manifest itself when the mean negative pressure exceeds about 6¾ lbs. per square inch, or when the whole thrust exceeds 11¼ lbs. per square inch. This is with blades of elliptical form, but it will probably vary somewhat when the surface is differently distributed.

Results in strict accordance with those of the "Daring" were obtained contemporaneously from the trials of two torpedo-boats. Nos. 91 and 92 are sister vessels and had screws of the same diameter and pitch, being made from the same drawing, but the surface of the screw of No. 92 was about 40 per cent. more than that of No. 91. At 24 knots per hour, the boat with the narrow blades required 16½ per cent. more power than the other, and the slip of the screw of No. 91 was 20 per cent., while that of No. 92 was 6 per cent. only. The negative pressure in the case of No. 91 is 9·8 lbs. per square inch, and in that of No. 92 it is 6·72 lbs., the latter figure, it will be observed, agreeing very closely with that at which the screws of the "Daring" commence to fall off in efficiency, viz., 6·75 lbs. There seems to be more than a coincidence in these figures, and the results appear to show that a new condition of things has been entered upon. The analysis of the speed-trials of a number of vessels built at Chiswick shows that in no previous case has the negative pressure exceeded 7 lbs. per square inch except in No. 93 torpedo-boat and in the "Speedy," where it amounted to 7·9 lbs. and 7·4 lbs. respectively, and it is probable that in No. 93 the blade-area is too small. The vessel passed out of Messrs. Thornycroft and Co.'s hands before the experiments described had taken place, or wider-bladed screws would have been fitted and tried.

The surface used in these calculations is the projected surface, because the thrust dealt with is sternward only. The improvement obtained with No. 4 screws at moderate speeds as compared with Nos. 1, 2, and 3 was probably due to the greater projected area obtained by twisting the blades to a finer pitch. More developed blade-area is required for screws of great pitch-ratio than for those in which the pitch-ratio is small; because the projected area of a given screw is inversely proportional to the pitch-ratio, and also because the ratio of negative to positive pressure becomes greater as the pitch-ratio is increased.[1] Mr. Normand has described what he calls the rupture of the column which occurs when air finds its way from the surface to the screw. He made some experiments with a moored vessel and ascertained the thrust obtainable with different immersions; but he dealt only with the case of free communication between the atmosphere and a screw or rudder by vortices or otherwise, when rupture takes place as soon as the speed at which the water is required to fill the void behind the propeller or rudder exceeds 14·5 feet per second or 8½ knots per hour, at a depth of 1 metre.

[1] Minutes of Proceedings Inst. C.E., vol. cii. p. 87.

It is apparent that if the Authors' reasoning is correct, the speed of vessels has now approached within measureable distance of that at which propulsion by screws depending upon the reaction of water, becomes inefficient. For a given pitch-ratio and slip, *i.e.*, at what is known as "given abscissa value," the thrust per unit of area varies as the square of the speed. Since the total thrust required to propel a ship at a given speed is a fixed quantity depending upon the resistance, it follows that cavitation can only be avoided at very high speeds, or, to be more exact, at speeds such that the critical ratio of thrust to area is reached, by increasing either the immersion of the screw or its blade-area. The immersion is usually governed by considerations of draught of water; and, provided it is sufficient to prevent air from penetrating from the surface, it is not practicable to obtain much benefit by lowering the screw. Increased blade-area may be obtained in three ways. 1st. By increasing the ratio of blade-area to disk-area. 2nd. By reducing the abscissa value, or, in other words, employing a larger diameter of propeller working at less slip than that theoretically best for the given conditions. 3rd. By increasing the pitch-ratio, which involves a larger diameter with a reduced rate of revolution. Either course tends to a waste of power if pursued beyond somewhat narrow limits, and it appears inevitable that reduced efficiency must be submitted to as the speed of vessels is increased.

The Paper is accompanied by eighteen sheets of tracings, from which Plate 1 and the *Figs.* in the text have been prepared.

[APPENDIX.

APPENDIX.

Tests of a Model Thornycroft Boiler.

Engineering Laboratory, King's College, London.
15th March, 1895.

Messrs. J. I. Thornycroft & Co., Chiswick.

Dear Sirs,—I have made a series of tests with the model boiler which you sent to me for trial, and have determined its efficiency for eight different rates of steaming at atmospheric pressure. The boiler with four rows of water-tubes each side and a total heating-surface of 12·4 square feet contains 4·1 lbs. of water up to datum-level. Gauge-marks were placed at each end of the steam-drum and the water-level sighted from end to end through the glass plates with which it was provided. In this way the level could be determined with great accuracy. With one exception the trials lasted for over half-an-hour; observations of gas, and feed-water, with feed and funnel temperatures being taken every five minutes.

Gas.—The gas was measured by a standard gas-meter made by Messrs. Alex. Wright & Co., which has been tested and certified correct by the Standards Department of the Board of Trade. This identical meter was used on the Society of Arts motor trials, and has a dial which can be read to the $\frac{1}{100}$ cubic foot. The pressure is measured by an ordinary water-gauge, and the temperatures of both inlet and outlet by standardized thermometers.

Water.—The feed was supplied from the rectangular copper tank accompanying the boiler. For measuring the quantity used, a float was provided graduated in pounds and half-pounds. By subsequent calibration I have found these graduations correct. Throughout each trial the level of the water in the boiler was maintained as nearly constant as possible, special care being taken that it should be brought to the datum-line at the end of each five minutes' interval when the observations were taken.

Temperatures.—The feed and funnel temperatures were measured on thermometers which have recently been standardized in my laboratory. The feed-water was allowed to stand for some time before use in buckets close to the boiler, so that its temperature was very steady at that of the room. The temperature of funnel gases was measured at the hottest point just below the level of the top of the steam-pipe.

Efficiency.—For calculating the boiler-efficiency the thermal value of the gas has been assumed equal to 19,000 B.T.U.'s per lb. This is the mean thermal value obtained from a number of analyses recently made for me by Mr. G. N. Huntly. Individual values did not differ from this mean by 2 per cent. in any case, although an interval of more than a year elapsed between the first and last observation. From the same analyses the value of K (difference between K_p and K_v) was determined = 130, and this value has been used for the calculation of the specific volume of the gas. For this purpose the temperature and pressure at the meter were observed during each test and the corresponding specific volume of the gas found.

The first trial made without any funnel gave such anomalous results that a

funnel 10 inches high was added for the subsequent experiments. Without a funnel the efficiency was only 38·8 per cent. when burning over 70 cubic feet of gas per hour.

It was incidentally found that any sudden variation in the rate of feed made a very marked reduction in the evaporation, and consequently in the efficiency. An accidental lowering in the water-level at the time of refilling the feed-tank made a rapid addition of feed necessary to bring the water in the boiler up to datum-level in time for an observation to be made. It was found that the evaporation during the subsequent five minutes was reduced to exactly one-half its mean value for the rest of the trial. This point was therefore carefully watched, with the result that any considerable irregularity of feed was invariably found to be accompanied by a perceptible slackening of the violence of ebullition, and, if aggravated, by a diminution in the rate of evaporation during the following interval.

The results of the experiments have been plotted on a base representing rates of transmission per square foot of heating-surface. It will be noticed (*Fig. 24*) that the line joining the tops of the ordinates representing efficiencies per cent. is very closely a fair curve. The efficiency increases in value as the rate of transmission is increased up to a maximum value of 86·8 per cent. when the rate of transmission is 22·35 B.T.U.'s per square foot per minute. It then gradually decreases in value until a rate of transmission of nearly 39·5 B.T.U.'s per square foot per minute is reached, when the efficiency is 68 per cent. From this point the efficiency very rapidly falls off, showing that the air-supply is not sufficient for the perfect combustion of the gas. Some means for artificially increasing the air-supply would be beneficial beyond this point.

A very valuable fact, which is for the first time shown by these experiments, is that the economy of model boilers may be under certain conditions as great as that of full-sized boilers of the same type. In some trials made by Prof. Kennedy, and recorded in the Minutes of Proceedings of the Institution of Civil Engineers, vol. xcix., Session 1889–90, a precisely similar efficiency of 86·8 per cent. was obtained with a Thornycroft boiler having 1,887 square feet of heating-surface at a rate of transmission of 23·8 B.T.U.'s per square foot heating-surface per minute. Should this comparison prove capable of general application, very considerable advantage might be derived from model boiler experiments.

A Table showing the results of the eight trials is appended; and a diagram giving the efficiency curve, quantities of gas used, and water evaporated for different rates of transmission (*Fig. 24*, p. 75), is also added.

I am, Gentlemen, Yours faithfully,

D. S. Capper.

TABLE.

Date	Feb. 26.	Feb. 26.	Feb. 25.	Feb. 25.	Feb. 25.	Feb. 26.	Feb. 28.	Feb. 28.
Duration (minutes) .	45	50	30	45	40	50	20	30
Atmospheric pressure (lbs. per sq. inch) .	14·67	14·71	14·66	14·66	14·66	14·64	14·75	14·77
Meter pressure (lbs. per sq. inch)	14·74	14·78	14·73	14·73	14·72	14·71	14·82	14·88
Gas per hour (cub. feet)	12·01	19·69	31·9	46·3	55·2	70·98	81·8	101·84
" " (lbs.) .	0·385	0·633	1·01	1·47	1·77	2·27	2·60	3·25
Thermal equivalent at 19,000 B.T.U. per lb.	7,315	12,030	19,190	27,930	33,630	43,090	49,320	61,690
Equivalent in lbs. of water per hour from and at 212° F. . .	7·58	12·45	19·82	28·91	34·8	44·6	51·06	63·85
Temperature of feed (°F.)	48·0	48·0	52·0	51·0	43·0	48·0	46·5	52·5
Factor of evaporation .	1·170	1·170	1·165	1·167	1·175	1·17	1·171	1·165
Feed-water (lbs. per hour)	4·2	8·34	14·79	20·4	22·8	25·92	27·00	28·392
Equivalent from and at 212° F.	4·91	9·76	17·23	23·81	26·96	30·33	31·62	33·084
Temperature of funnel-gases (°F.) . . .	..	..	228	238	220	227	252	245
Heating-surface (sq. ft.)	12·4	12·4	12·4	12·4	12·4	12·4	12·4	12·4
Water evaporated in lbs. per square foot of heating-surface per hour	0·338	0·675	1·195	1·64	1·85	2·09	2·175	2·29
Mean rate of transmission of heat (B.T.U. per square foot heating-surface per minute) .	6·475	12·66	22·35	30·9	35·0	39·38	41·05	42·95
Efficiency of boiler (per cent.) . . .	64·7	78·5	86·8	82·2	77·5	68·0	61·9	51·8

[DISCUSSION.

Discussion.

Mr. W. H. PREECE, C.B., Vice-President, said all who were present must have recognized the extremely clear and able way in which the Authors had brought a most interesting subject before the Institution. Not only did the members attest by their number the interest of the Paper, but their applause had almost anticipated the proposition which it was his pleasure to make—that a hearty vote of thanks be accorded to the Authors. Mr. Preece.

Mr. J. I. THORNYCROFT, after referring to the Table (Appendix I) of the experiments made with the small model boiler by Prof. Capper, exhibited and described twenty-seven lantern-slides of a number of vessels illustrating the subject of the Paper. He afterwards showed the model boiler at work, in which the circulation of water could be seen, and demonstrated by aid of a model the effect of the distortion of an ordinary crank due to the turning-moment transmitted through it. Mr. Thornycroft.

Mr. A. F. YARROW thought the details of the "Daring" would be made more complete if the Authors would give the displacement at the commencement of the three hours' run. He did not think that was stated in the Paper, but it was essential in order to form a correct opinion as to the efficiency obtained. It might, perhaps, be interesting to the members to know the results obtained by his firm in the case of the "Havock" and the "Hornet" class of destroyers, so as to compare the power and speed obtained with the curves which the Authors had given. The progressive trials of the "Hornet" showed the following powers and speeds: 11·3 knots per hour with 207 HP.; 16·7 knots with 1,200 HP.; 23·4 knots with 2,700 HP.; and 27·6 knots with 3,884 HP., the last being the speed at the official trial. At that speed the mean air-pressure in the stokehold during three hours was 1·6 inch head of water, showing a large margin of boiler-power in excess of what was required. The "Hornet" at the time of the trial had a displacement of 220 tons. In comparing the weights of the boilers, the Authors gave the weight of the boilers in the "Daring" with water and mountings complete, including up-takes but without the funnels, at 48½ tons. In the "Hornet," which had 8,200 square feet of efficient heating-surface and 173 square feet of grate-surface, the weight of the boilers, including the same items, was 43 tons. As to the pro- Mr. Yarrow.

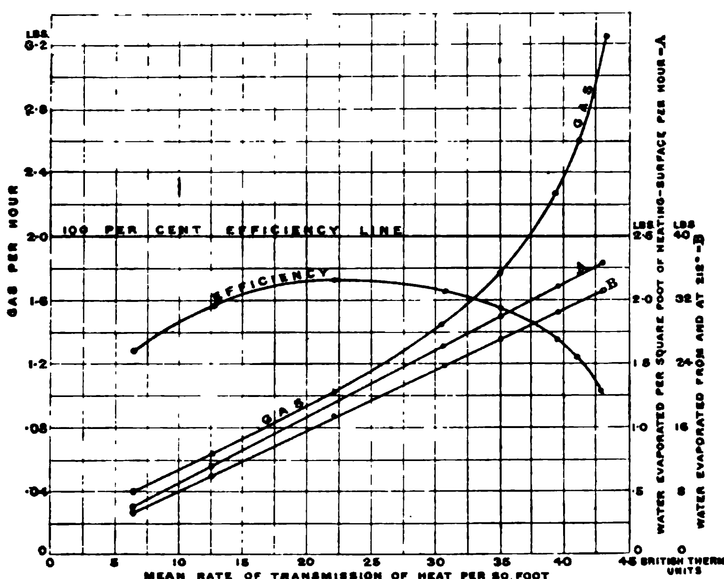
Mr. Yarrow. portions of the propellers and the great gain shown by an increased area, to which the Authors had referred, it would add to the value of the Paper if it were stated what those areas were; because in the description it was simply stated that in the efficient screws the blade-area was increased by 45 per cent., but the areas or diameters of those formerly used were not given. He might say that in the destroyers built by his firm, propellers had been adopted of 6 feet 6 inches diameter and 8 feet uniform pitch, the three blades of each propeller having a total developed area of about 1,700 square inches. In the "Hornet" with 3,884 I.HP. a speed of 27·6 knots per hour was obtained, with a slip of 11 per cent. In the "Havock" at the speed of 26½ knots per hour the slip was 9 per cent. It might be interesting to note that one of the first boats built of about the same size as the present destroyers, was the "Kodaka," constructed by his firm for the Japanese Government in the year 1885. She was 170 feet in length by 19 feet 6 inches beam, and a peculiarity of the vessel lay in her being armour-plated with 1-inch plates throughout the boiler and engine compartment, both on deck, along the sides, and at the ends of the machinery space. The official reports of the performance of the vessel during the war were to the effect that the armour-plating had been a source of immense advantage, and it was this vessel which had led the successful torpedo attack at Port Arthur.[1] She also took a leading part in the attack at Wei-Hai-Wei, coming out with comparatively little injury, owing to the armour-plating. It might, perhaps, be a question for Governments to consider whether the increased protection secured by the armour-plating might not be well worth the reduction of speed which it involved.

Prof. Capper. Prof. D. S. Capper observed with reference to the series of trials which he had made with the model Thornycroft boiler exhibited, that it had at first been intended merely to determine the efficiency of the model so as to compare it with a full-sized boiler of the same type. The boiler had a heating-surface of 12·4 square feet, and when filled to working-level contained 4 lbs. of water. A complete report of the trials with a Table of the results was given in the Appendix to the Paper. One of the first trials made was that given in the third column of the Table. With a mean rate of transmission of 22·35 British thermal units per square foot of heating-surface per minute, the water evaporated per square foot of heating-surface per hour was 1·195 lbs., and the efficiency was 86·8 per cent. On comparing this with the trials made by

[1] *The Times*, November 24, 1894, p. 9.

Dr. A. B. W. Kennedy on a Thornycroft boiler having 1,837 square feet of heating-surface, with a rate of transmission of 23·8 British thermal units per square foot heating-surface per minute, and water evaporated equal to 1·24 lbs. per square foot of heating-surface per hour, it appeared that the same efficiency had been obtained. This result was so striking that a series of trials at progressive rates of steaming had been carried out. The trials were all conducted at atmospheric pressure, the arrangements not being such as to permit of working at higher pressures. It might also be pointed out that there was no means at hand for artificially increas- Prof. Capper.

Fig. 24.



ing the air-supply, and consequently the rate of transmission of heat, *i.e.*, the rate of steaming, could only be increased by increasing the gas-supply. He thought the result of that would clearly be seen in the efficiency-curve, *Fig. 24.* The 100 per cent. efficiency-line was shown on the diagram, and the curve crossing it showed at each rate of steaming the efficiency as compared with perfect efficiency; starting with a rate of transmission of 6·4 British thermal units per square foot per minute, an efficiency of 64·7 per cent. was obtained, from which point the curve rose gradually up to its maximum value, 86·8 per cent. as already stated. After the maximum was reached, the efficiency decreased more and more

Prof. Capper. rapidly until at a rate of transmission of 42·95 British thermal units per square foot per minute, it was 51·8 per cent. In Dr. Kennedy's trials that fall was not nearly so rapid, for at a rate of transmission of 158 British thermal units per square foot per minute he had obtained an efficiency of 66·6 per cent. This divergence was most probably due to the incomplete combustion of the gas in consequence of deficient air-supply in the experiments with the model after the maximum point had been reached. There were distinct signs that this was taking place during these trials. He thought it was highly probable that if experiments were carried out with a properly arranged artificial air-supply, the curve of model efficiencies would approach much more closely at its latter end to that of the full-sized boiler.

The first part of the curve was the most interesting and important, and clearly showed that in this case at least, experiments with a model having less than 12½ square feet of heating-surface were comparable with the results obtained with a boiler having a heating-surface nearly 150 times as great. The thermal value of the gas used had been taken as 19,000 British thermal units per lb., this being the average of a number of analyses made by Mr. G. N. Huntly. These analyses differed little, although the samples were taken at long intervals—the last of them within a month of the trial. He thought that value could be adopted as accurate, although the gas was not analysed during the trials. Taking that figure, 1 lb. of gas was equivalent in heating-value to 1·32 lbs. of carbon; and at its maximum efficiency the model boiler therefore evaporated 13·02 lbs. of water from and at 212° F. per lb. of carbon value. That was a remarkable result in a boiler of the size referred to, and seemed to indicate that the type of boiler under consideration was as efficient on a small as on a large scale.

It had been pointed out by the Authors that they had invariably found when the speed of the engine exceeded a certain amount, the power seemed to be underlogged. It was a very interesting matter, which called in question the accuracy of the indicator. He would like to hear how far it was found that the power was underlogged, or that it was suspected of being underlogged. It was difficult to carry out experiments with an indicator in such a way as truly to compare its indications with any scientific standard when running at a high speed, and thus to determine its errors under working conditions. He had made a number of experiments bearing on that point on an apparatus he had devised for the purpose. A steam-cylinder was suitably connected with

a mercurial column so that pressures in the cylinder could be read directly in inches of mercury. He had found that if the pressure was suddenly applied by opening the cock of the indicator, the pressure recorded by the latter was invariably less than the true pressure as shown on the column. And that this difference was not due to any drop in the pressure of the steam-cylinder on opening the indicator-cock, was shown by the indications of a gauge attached to the cylinder. He was aware that gauge-readings were not to be relied on for absolute readings; but for checking differences of pressure they could be made to all practical requirement reliable. Those results seemed to point in the same direction as the underlogging of power recorded by the Authors, but his experiments, though extensive, were not sufficient in number and range to warrant him in asserting definitely that similar results would always be obtained. He thought the Authors were to be congratulated on having pointed to a limit being possibly obtained, in one direction at least, in the complicated problem of propellers; and the results which had been shown in connection with cavitation were extremely interesting and valuable. Prof. Capper.

Mr. A. E. Seaton asked if the float arrangement in the boiler was found to work fairly accurately, because he thought in a boiler of that kind, which was a pronouncedly priming boiler, there might be some difficulty in regulating the flow. He agreed in the advisability of providing such an apparatus. With respect to the screw-propellers, he prided himself in having predicted twelve months ago failure for the first of the type referred to in the Paper. He had told Mr. Thornycroft, Jun. (who had been good enough to give him the particulars of the propeller), nearly what would happen, not only as to failure of speed but as to the general results of its working. He had likewise indicated the area that he would recommend, which was, he thought, 45 per cent. greater than Messrs. Thornycroft had then fitted. He only mentioned these matters to show that the subject might be worked out without such an amount of scientific investigation as the Authors had favoured the Institution with. The Admiralty had been good enough to give his firm an order for some similar boats, and the first thing he considered was how he could strike out an original line; this he had done more in the construction of the engines than in the boilers, because at the last moment his firm was called upon to use one of three or four boiler-types that had been tried. Unfortunately there were not at Hull the sheltered harbours that existed on the Clyde, nor a long river as in the case of London. So far the weather had prevented Mr. Seaton.

Mr. Seaton. him from carrying out many experiments. One had, however, been successfully made. A boiler-tube had broken, and had not been discovered for half-an-hour, thus showing that that class of boiler was safer than had been anticipated at the outset. He would like to have the information which had been asked for by Mr. Yarrow, but at the same time he could not help thinking that it was trespassing on the Authors' generosity. A most interesting experiment, to his mind, was that shown with the crank-shaft. He had not seen such an experiment before, but it bore out an investigation he had made some years ago as to the action on the after-most bearing in an ordinary steamship. He was convinced that the breaking of crank-shafts was not due to the causes to which it was generally attributed, and the experiment shown by Mr. Thornycroft had confirmed that view. With the simplest apparatus, the Authors had shown that a great benefit could be obtained by an apparently slight alteration in the form of the shaft. The experiment shown with the model boiler was most interesting, as was also the statement made by Prof. Capper as to the comparative results of the model and a full-sized boiler. In the future manufacturers would be enabled to place models of their boilers in the hands of engineers and have them examined, without going to the expense of making full-sized boilers; and that, he thought, was most important—not only as saving in first cost, but as enabling experiments to be made which previously had been unthought of. He believed there was a great future for the water-tube boiler, in spite of the accidents that were heard of. Notwithstanding the attacks so freely made on the system, it was one which would survive, and a development would be seen in the future such as had not before been experienced in any branch of engineering. Experiments with water-tube boilers had been made long before he or any member present was born. In the early days of the present century, the pioneers of steam-engine engineering had made such experiments as Mr. Thornycroft had alluded to, and they were apparently quite as inventive as that gentleman or his coadjutors. That they had not succeeded was due to causes then beyond their control, and Mr. Seaton did not think much benefit could be derived from their experiments, inasmuch as the records had been so long buried in the past. In a Paper read before Section G of the British Association, in 1894,[1] Sir Frederick Bramwell had alluded to what had been done in his younger days with road-carriages;

[1] *The Engineer*, August 17, 1894, vol. lxxvii. p. 152.

that was a subject which between 1825 and 1835 had occupied the engineering world very largely. In looking back upon the work of that period, it was interesting to find that engineers then were almost as advanced as those of the present day; inasmuch as the boiler which had been exhibited did not differ materially from that of Mr. Goldsworth Gurney, patented in 1827. The coil boiler, generally attributed to Herreshoff, was older still. A boiler worked in America in 1805—it was interesting to know that it had been suggested and introduced for marine purposes—did not differ largely from that of Mr. Yarrow's design; indeed, the tubes were of equal length in both boilers. They had been made of copper—he did not know whether that had been the cause of their failure—but they were eventually discarded. Mr. Seaton.

Rear-Admiral C. C. P. FitzGerald, without entering into the technical part of the subject or appraising the differences between experts, thought, from a general view of the question, a class of vessel had been produced to meet the present requirements. It was felt throughout the Navy that most valuable vessels had been produced as the outcome of the highest ingenuity and engineering skill. A sketch of the development of the torpedo-boat destroyers, from the enlarged torpedo-boat to the "Halcyon," had been given by the Authors, who had modestly sandwiched the "Daring" into the series. He should have placed the last-mentioned vessel outside the series and considerably above any of those which had been referred to, because she was one with reduced tonnage and increased speed, which was what was wanted. The development had been somewhat curious. The enlarged torpedo-boat had been dropped, and the "Rattlesnake" resorted to, but she had been found not sufficiently fast or sea-worthy. The "Speedy" had then been built, with larger tonnage and more sea-going power, but no greater speed, and then the "Halcyon," 1,070 tons, with a larger armament and a slight reduction in speed. They had been called torpedo-boat destroyers or catchers, which was a misnomer, as they certainly never could have caught a torpedo-boat, and consequently could not have destroyed it. During that period of development, Mr. Thornycroft appeared to have retired from the scene; but, when he had been called upon to do so, he had gone back to 200 tons and produced an increase in speed of 7 knots, which was undoubtedly a marvellous development. He did not see why the horizontal screen, Figs. 6, Plate 1, should not act, but he did not like it from a nautical point of view, because it might come up just when it was wanted to stay down, and *vice versâ*. He should like to see a more solid and permanent fitting; for there Rear-Admiral FitzGerald.

Rear-Admiral FitzGerald. was no doubt that in the case of one vessel chasing another, the arrangement of the bow-gun was an important matter. If anything could be done to keep the spray out of the men's eyes, it would add greatly to the accuracy of fire. The question of colour, with regard to which the Authors had mentioned that birds of a variegated colour were less visible than those of one fixed colour, might, and he hoped would be, made the subject of experiment. The "Daring" appeared to be a marvellous production of engineering ingenuity and skill, and deserved the highest approbation. There was one point of technical detail with regard to the great rudder-heads of 7-inch steel shafting, to which he should like to refer. No doubt Mr. Thornycroft had considered such weight was necessary to obtain the speed and turning-power. The wonderful development in torpedo-boats was due, he thought, largely to the healthy rivalry which existed between the great torpedo-boat firms. Towards the conclusion of the Paper the Authors had stated that the limit of speed which could be efficiently obtained by the screw had been nearly reached. If higher speed could not be obtained with the screw, something else must be tried, for the Navy would never be satisfied with any finality in speed; engineers would have to find some other means of propulsion, and never tell seamen that any speed was the highest that could be attained.

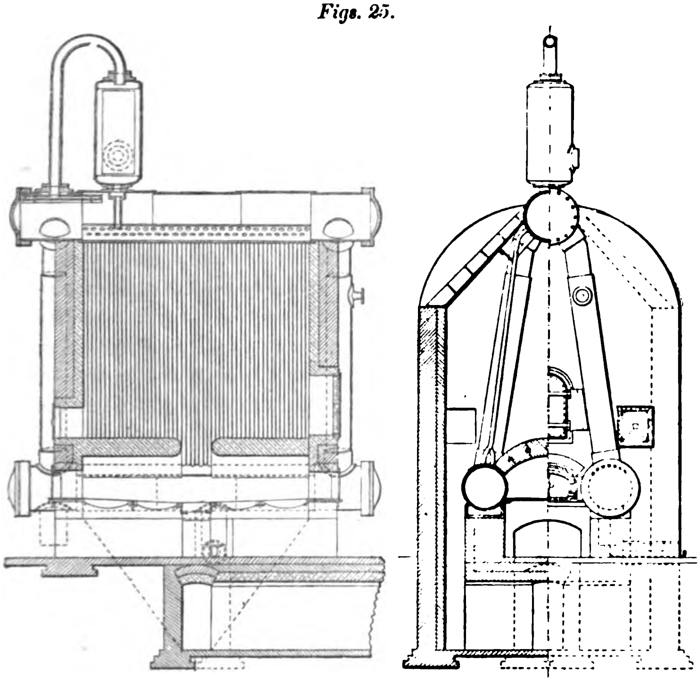
Mr. Halpin. Mr. Druitt Halpin mentioned that in 1880 and 1881 he had tested a water-tube boiler designed by Mr. Fryor in 1874, *Figs. 25*, which had worked very successfully. The boiler had three tubes, a large one at the top and two at the bottom with large connecting down-comer tubes at each end and small tubes between the large top and bottom horizontal tubes. There were two furnaces, the gas passing between the tubes. It also had one of the first systematic arrangements for circulation, separate down-comer pipes 1 foot in diameter being supplied.[1] There were four such pipes, two at each end, quite outside the boiler, and the water could return downwards vertically through them, ascending through the smaller pipes, which were exposed to the fire. The boiler had 28 square feet of grate, and 573 square feet of heating-surface. It was a double-fired boiler with one furnace at each end, so that the smoke from one fire was more or less consumed by the other; the combustion was perfect, and was greatly assisted by a fire-arch. It was not used for marine work, but was simply

[1] An earlier design, Patent No. 12514 of 1849, by Messrs. Clarke and Motley, shows separate down-comer pipes to produce circulation.

Mr. Halpin.

a boiler designed and built for use on land before torpedo-boats had been invented. He had made experiments at Mr. Yarrow's works some years ago upon a boiler of exactly similar design to those of torpedo-boats, but to work on land, so that the question of weight was not a matter for consideration. In spite of that, however, the boiler was very light, weighing only 2½ tons. It had 7 feet of grate-area, and 364 superficial feet of heating-surface. The results showed that the boiler was evaporating 2,330 lbs. of water per hour at 200 lbs. per

Figs. 25.



Scale ⅛ inch = 1 foot.

square inch. It was driven at the rate of 53 lbs. of coal per square foot per hour. There had been no calorimeter, and he could not speak with accuracy as to the dryness of the steam; but as far as it was possible to judge by the eye and ear, and by putting the hand in the steam, it was absolutely dry, and he had never had a trial run with greater comfort or with less trouble, even at that rate. The total length of the boiler was 8 feet and the width was 4 feet 8 inches. Steam was produced at

Mr. Halpin. the rate of 63½ lbs. of steam per hour per square foot of ground occupied. A Lancashire boiler 30 feet by 7 feet 6 inches, would occupy 350 square feet, and give between 5,000 lbs. and 6,000 lbs. of steam per hour, or only 15½ lbs. of steam per square foot of surface occupied. Whilst worked at the rate of 53 lbs. of coal per square foot per hour, the boiler evaporated 7·57 lbs. of water per lb. of coal calculated from and at 212° F. He had not analysed the coal, but it was of the best Welsh quality. Assuming that its calorific value was 15,000, it would give about 48 per cent. thermal efficiency, which he considered exceedingly good under the conditions at which the boiler was driven. An interesting Table had been furnished by Prof. Capper, and if it was true that it was possible from model boilers to obtain figures which would be of use in large boilers, it was exceedingly valuable. In regard to the figures as compared with the test made by Dr. Kennedy, they were so near, and there were so many in parallel that it appeared as if the law indicated must be true, and as if it were not a mere series of coincidences. It appeared to him that the only flaw in the argument was that the model boiler was working at atmospheric pressure, whilst a full-sized boiler worked at 150 lbs. or 200 lbs. per square inch. The conditions were then very different, the specific gravity of the water varying 10 per cent., and the weight of the steam by hundreds per cent.; so that it was doubtful whether it would be absolutely safe under those circumstances to use models, giving steam of such different quality from the steam produced in the real boilers, and to draw conclusions from the results. He would be glad if Prof. Capper could make an addition to the Table (Appendix I) which would render it more valuable, by stating the temperature at the Bunsen burner; because it would then be possible from all the data to calculate what the real transmissions were. The temperatures of the escaping gases were given in the Table for all except the first two experiments; and in the case of the third experiment of the 25th February, there was the anomalous result that with the smallest difference of final temperature, which in that case was only 8° F., one of the highest transmissions of heat, viz., 35 B. T. U. per square foot per minute, was obtained. If it were possible to give the initial and the final temperatures of the hot gases, the mean temperature could then be deduced, the thermal head obtained, and the conditions be known more completely. The efficiencies taken from the Table were very good, averaging 71·4 per cent. A result as high as 86·8 per cent. had been obtained, and those who had achieved it should be heartily congratulated. The efficiencies

obtained by Dr. Kennedy with the last large boiler were equally good. He understood that trial had been of a short duration of four or five hours, but he could mention four tests of 72 hours, 72 hours, 168 hours, and 168 hours' duration respectively made with a Lancashire boiler. The water and the coal had been carefully measured, and during the periods referred to—which of course meant clearing fires, night work, day work, Sunday work and the like—the efficiency had averaged 86·5 per cent. Mr. Halpin.

Mr. A. MALLOCK said, with reference to the work he had done in balancing the engines of the "Daring," the diagrams, Figs. 17, Plate 1, showed the effect on the engines during revolution. They consisted of a series of ellipses, the meaning being that the radius represented the force which acted on the engine at the crank when it was in a certain position defined by the radius of the circle. With every crank and eccentric, every moving part, there would be an ellipse of that kind formed, and when those ellipses were combined, taking the resultants of those forces in their order, they gave the total resultant force acting on the shaft. In the same way, by taking the moments of those forces about the centre of gravity of the moving parts, the resultant couple acting on the engine was obtained. All those forces and couples were of course reducible to a single force and a single couple; and if the necessary weights were applied in the shape of balances, the force acting on the engine would be balanced, in so far as it was simply a harmonic force acting once per revolution. But it had been brought out lately with some prominence that the shortness of the connecting-rods had an important effect on the balance of the engine. The force which acted on the engine was not a simple harmonic force, but had other terms in it. The chief effect of the shortness of the connecting-rod was to introduce a force acting on the engine, which had the same effect as $\frac{r}{4l}$ times the moving mass would have if revolving at twice the speed of the engine—r and l being the radius of the crank and the length of the connecting-rod respectively. That was a considerable force, and was the more important from the fact that it changed its sign so often. It had twice the frequency of the engine. The importance of small vibrations was only coming into prominence. Supposing a ship to be set in vibration by the engine, it would require an amplitude of vibration of $\frac{1}{2}$ inch when the engines were running at 250 revolutions per minute to produce an accelerating force equal to g. Taking 1,500 vibrations Mr. Mallock.

Mr. Mallock. per minute, which he had often observed with an engine running at 250 revolutions per minute, $\frac{1}{100}$ inch in amplitude would give the same force. This amplitude was occasionally reached by the quick vibrations, and on the whole he thought that they caused more inconvenience than slower vibration with larger amplitude; because in the former case, when the upward acceleration was the greatest, the slightest sideways force would set in motion anything held in its place merely by gravity. In connection with the vibration of ships, it had lately been pointed out by several persons that it was important to know beforehand, if possible, where the nodes or stationary places of a ship would be when the vibrations were being executed, because it was possible to avoid vibration by disposing the moving masses in such a way as to be in the proper relation to those nodes. He had placed on the table an apparatus by which, with the aid of models, the position of the nodes in any ship could be determined beforehand. He might illustrate his remarks by a plank which he exhibited, which was the dynamical analogue of a ship as far as regarded oscillations in a vertical plane. It was a plank of uniform thickness, the profile of which was a curve with ordinates proportional to the bending-moments of the ship, the loads on it being proportional to the curve of loads. A plank of that kind was equivalent, in regard to vertical vibration, to the ship. Any disposition of load could be placed upon it. An abrupt variation in the strength of the ship would be represented by an abrupt difference of breadth in the plank, and an abrupt change of load would be represented by a discontinuous disposition of the load on the plank.

Mr. Terry. Mr. S. H. TERRY thought that the models exhibited by the Authors probably explained many a mysterious failure in a crank-shaft, and also illustrated the importance of dealing with any force due to pressure and momentum at the precise spot where the effects of that force were felt, instead of storing up these pressures to be imperfectly controlled at an adjacent bearing. In experiments which had been made as to the continuity of turning and immunity from vibration of different types of engines, viz., one-, two- and three-crank engines, in all cases a marked improvement had been found in the action of the last-mentioned type. At first sight it might be supposed that the uniformity of turning would be greater with the three-crank engine, but that there would be less vibration with a two-crank twin-engine with cranks at 180°. That, however, was not the case, and the three-crank engine showed not only greater uniformity of turning, but also superior freedom from vibration. The explanation of the matter had been recently very

lucidly given by Mr. M. Robinson and Capt. M. H. P. R. Sankey.[1] Mr. Terry. Probably, with the types illustrated in Figs. 15 and 17, Plate 1, a very uniform turning-effort would be exerted. It might be learned from the Tables given by the Authors, and from the performance of certain boats with different types of water-tube boilers and locomotives, that where extremely high speeds were required, as in the case of vessels of great lightness in relation to the power expected from them, some form of water-tube boiler must be employed. He did not say that that was necessarily the case with mail-steamships and cargo-boats; but in the case of small fast craft it was certainly so.

Mr. A. Rigg remarked that the Paper dealt with a subject of which Mr. Rigg. few persons outside the firms which built torpedo-boat engines had sufficient experience to enable them to discuss it. With regard to the steering-gear and rudders, Figs. 13, Plate 1, it was an excellent arrangement, and that for several reasons which the Paper did not set forth. The boat prevented the air from entering at the top, and the side rudders not only guarded the screw but also protected it from air going in at the sides. The screw-propeller was single, with blades turned backwards for the purpose of overcoming the centrifugal force of the water, which at a high speed must be enormous. He had made many experiments with screw-propellers, and his conclusion was that, whatever else happened, the water left the blade vertically. There were many types of propellers made, but he thought that four blades were in some respects better than three; that, however, might be due to his having experimented with larger screws and lower velocities than those used by the Authors. It occurred to him that the horizontal vibration described in the diagram might be to some extent counteracted by the motion of the slide-valves. The cranks appeared to him to have too many sharp corners, because it was notorious that of whatever the material the shafts were made, such corners should be well rounded or fracture was inevitable; but probably the figure was only a diagram and was not accurate in regard to such details. There were two systems of running high-speed engines. One was the rigid system, in which case the shaft was made of great strength, and the other was the flexible system. The engines of a torpedo-boat ought to be on the elastic or flexible system. The bearings described were apparently rigid, but he should have thought it

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[1] Transactions Inst. Naval Architects, 5 April, 1894. "On a Method of Extinguishing Vibrations in Marine Engines."

Mr. Rigg. would have been an improvement to make them slightly movable. The shaft would bend and the bearings would be always free, and would be more durable than if they were kept too rigid. His opinion was that there was no such thing as slip of a screw, and that it was a misnomer in every way. It assumed that the screw-propeller should go through water as a solid body. It really acted as an oblique paddle. By regarding the propeller as an oblique paddle, it gave a good screw to work the ship, but taken as a true screw it was a bad propeller, because no one treated it in practice as if the theory was correct. By comparing the performances of a true screw and a flat board or blade, the latter would give the best result so long as it had sufficient "pitch." The experiments described showed much the same thing, and if the information given in the Paper were digested it would prove extremely valuable not only to builders of torpedo-boats, but to that far more extended class who used screw-propellers, and who sought in vain among writers on the subject to find anything better than "rule of thumb" to guide to a correct form suitable to any particular vessel.

Mr. Beaumont. Mr. W. W. Beaumont could not agree with the remarks of Mr. Rigg with regard to flexible bearings and securing the means for permitting crank-shafts to bend. He thought if there was any part that should be rigid, in an engine of the kind referred to in the Paper, it was that which carried the crank-bearings. Assuming that the crank and bearings and all such parts were perfectly true to begin with, they could not be too rigid, and the bearings could not be too near to their work or to the pressure that had to be brought to bear upon them. If flexibility was to be introduced anywhere, it was certainly not in the part where the bearings were necessarily close together. Anything like bendings, repeated in exactly opposite directions as they were, with so great a rate of revolution, must ultimately result in fracture of the crank-shaft. With reference to the balancing of the engines, it would be seen that calculations were made showing what must be the weight of bob-weights, or equivalent bob-weights, to meet and resist certain disturbing forces. He thought it might be shown with regard to vertical forces brought to bear in the engines, that they might be balanced within a small amount by means that were commonly known—including the question of obliquity on the connecting-rod and of the difference in the velocity at the different parts of the stroke. It was well known that Mr. Yarrow had done a great deal in that direction by means of bob-weights which had a vertical motion. It appeared to Mr. Beaumont, guided by what

he had done in other directions in making use of the forces that were set up by unbalanced masses, that by using bob-weights, or weights that were moved by forces originating vibration, the excess of weight necessary to balance the vertical forces might be employed in a horizontal instead of a vertical direction; or in some cases they might be used, if not horizontally, at an angle that should be determined by the balance that had to be effected. If, instead of using vertical bob-weights, for instance, there were weights either suspended or allowed to slide, the forces that had to be dissipated, as otherwise setting up vibratory effects, might be used to move those weights either horizontal or nearly so. It would be found that the paths of the force, or curve representing the force, as set out by Mr. Mallock, and shown on the diagram, Figs. 17, Plate 1, might be converted into circular paths; and in that case, the unbalanced forces might be reduced to so small a value that it would not be a question so much of what the positions of the nodes of the vessel were, as one of the engine, so as to make the ship-builder independent of that consideration altogether. He thought it was quite impossible to arrange matters in such a way that the loads in a ship should always be the same. The cargo changing, and also the speed, would make the nodes vary in position; and it therefore seemed to him to be necessary that the engine should receive all the attention possible, and that the work which had been done by Mr. Yarrow and Mr. Mallock should be developed in such a way as to obliterate those forces tending to produce vibration, rather than that attempts should be made to cause ships to suit the vibratory tendency of those waste forces in unbalanced engines. Mr. Beaumont.

Mr. DARNTON HUTTON considered that the Paper contained many entirely novel points. He knew something of the "Daring," and had received a letter from one of her officers, stating that the engines and boilers, especially the latter, had given unqualified satisfaction. With reference to the spray-guard, it was perfectly true that it was a difficult thing, on account of the spray, to lay the guns at full speed; but there was a greater difficulty still, as to which he could testify from personal experience, namely, that the vibration made the sights jump so much that it was not possible to lay the guns with precision when going at full speed. The usual way was to stop the engines for a minute or so, take aim, and then to fire and go on again. It would be interesting to know whether some additional speed could not be obtained by cutting away the fore-foot of the ship, as was now done in the case of racing vessels. It would tend to reduce the surface-friction. The Authors might Mr. Hutton.

Mr. Hutton. perhaps state the surface-resistance and the wave-resistance at different speeds, as the information would be exceedingly interesting.

Prof. Greenhill. Professor A. G. Greenhill expressed surprise at hearing that the Authors were beginning to lose confidence in their old ally the screw-propeller, and to fear that it would not continue to respond to all the increasing demands made upon it. He did not share those misgivings, especially as he had read in the Paper that an increase of the blade-area in the propellers of the "Daring" was sufficient to overcome the difficulty; and he thought that in time the screw-propeller would approximate to the shape of the Archimedean screw of the early inventors. No difficulty had been felt in the use of the turbine and Pelton wheel under the highest water-pressure; and the screw-propeller ought also to work equally well under more serious and more arduous conditions, considering that the dynamical theory was the same for those two classes of engines. He hoped that the Authors would continue their valuable experiments with model screw-propellers, especially since those experiments might be made indoors in the laboratory. The experiments could be carried out in an artificially created current of water moving with high velocities to imitate the conditions attained in high-speed torpedo-boats—speeds of 30 knots or 40 knots per hour, or even higher. Such currents could easily be obtained from the mains of the Hydraulic Power Company.

Mr. McGregor. Mr. J. McGregor could hardly agree that experiments with model boilers were likely to form a basis of calculation for the construction of large boilers. He did not think there had been any law deduced from the experiments referred to with the model boiler, by which the performance of large boilers could be ascertained. The conditions of the experiments were so different from those of actual practice that it was a difficult thing to apply them in any way. He did not follow the results stated; *e.g.*, the mean rate of transmission per square foot of heating-surface per minute in the first experiment was 6 units, in the second 12 units, then 22 units and 30 units. Those figures were so small as compared with the results obtained by the Research Committee of the Institution of Mechanical Engineers on Marine-Engine Trials, that he hardly understood how they could be applied in practice. The figures obtained by that Committee were between 51 units and 159 units. With reference to the temperature of the gases, he observed that they had been ejected at temperatures of 228° F., 238° F., and 220° F.—a few degrees above boiling-point—so that the amount of fuel burned in the boiler must have been small in relation to the heating-surface. With regard to the efficiencies—

64 per cent., 78 per cent., 86 per cent., and 82 per cent.—he believed that the efficiencies of ordinary steam-boilers were seldom above 70 per cent. One result, indeed, of the Research Committee went as far as 84 per cent., but that was rejected as untrustworthy. [Mr. BARNABY asked if water-tube boilers were used.] Water-tube boilers had not been used. He was alluding to ordinary heating-surface. He would, therefore, like to know more about the trials where such high rates of efficiency were obtained. They were undoubtedly interesting, but he did not see that they could be profitably applied in the way suggested. Mr. McGregor.

Mr. MARK ROBINSON said that what might be called one of the by-subjects of the Paper, which had come into prominence during the discussion—viz., the question of vibration, was a subject to which his colleague, Captain Sankey, and he had lately given a great deal of attention. They had learned from the Author that the "Daring's" four-crank engines had given good results in respect to freedom from vibration. Various views had been expressed on the subject, which he would be sorry to attempt to discuss without more preparation; but he thought the influence of the obliquity of the connecting-rod was now recognised, and that soon a useful and practical theory of the vibration of marine-engines would be arrived at, and would be the means of stopping it. Reference had been made to the position of vibratory nodes in the ship, and to the importance of so placing the engines with reference to the nodal points that the vibration set up should not be communicated to the ship. No doubt that was a very important subject of investigation, but the line which Captain Sankey and he had taken up was that it was better to get engines altogether free from vibration. Ordinary engines gave rise to forces due to inertia which might of course be resolved into a couple and into a force; but in an engine which had three cranks equally spaced, or four cranks equally spaced, and all its parts of equal weight, there was nothing but the couple to deal with, and no other inertia force. The "Daring" had four-crank engines, but the moving parts were not of equal weight. He did not know that they differed largely from equality, because the low-pressure cylinder was divided into two; in any case a good result was given. If an engine was not produced which had neither couple nor vertical force to deal with, the next best thing was to have an engine which had a couple, but which eliminated, or nearly eliminated, the vertical force. Mr. Robinson.

Mr. C. H. WINGFIELD said there were no sharp corners where the section of the crank-shafts shown in Fig. 15, Plate 1, changed; Mr. Wingfield.

Mr. Wingfield. the corners between the flat and cylindrical parts were rounded to a large radius. The small loads that were imposed on the main journals conduced to cool bearings. The two L-P. pistons were of the same size, and when one was pushing the crank-shaft down the other was pulling it up, and a couple was thus formed tending to tilt the shaft. The resistance of the bearings, which were about three times as far apart as the two crank-pins, formed an opposing couple. The pressure on each bearing would then be about one-third of the load on one piston. With the more usual arrangement of two bearings for each crank, the pressure on each was about one-half the load on the piston. The direct result of the design therefore was that the pressure on the main bearings and the tendency to heat was two-thirds of what it would be with similar cylinders having twice the number of bearings and a crank-shaft of the usual design. The indicator-springs had been referred to by Professor Capper. He should like to know how the proper temperature at which to test indicator-springs was usually determined. If the strength varied at different temperatures of the springs, a spring which gave a correct reading for the initial pressure on an indicator-card would not be correct when indicating the back-pressure line, since the spring was then exposed to cooler steam and its readings would be to a different scale. Probably the best temperature at which to test them would be a mean between the maximum and minimum to which they would be exposed when in use. He had tested a safety-valve spring while it was surrounded by water kept boiling by a gas-jet, and there had been no sensible difference between the load required to produce a given deflection under these conditions and when cold. The arrangement of cranks shown in Figs. 14 and 15, Plate 1, led to a more regular turning-moment than was at first apparent. Since two adjacent pistons reached the ends of their strokes simultaneously, the resulting twisting-moment was identical with what was found in engines having cranks opposite and cylinders parallel. At first sight such a pair of cranks might be supposed to have a turning-moment as irregular as a single crank and single cylinder, so that the dotted line *c* in *Fig. 26* would represent two superimposed crank-effort diagrams (one for each cylinder) which when combined gave the full curve *d*. On referring to *Fig. 27* it would be seen that if one piston P_1 were put in the centre of its stroke, the other one P_2 would be some distance past it, and the crank-effort diagrams $c\,c^1$ (*Fig. 28*) being thus relatively displaced, the combined curve *d* was flatter than that in *Fig. 26*, showing that the turning-moment was more uniform. When this was combined with the curves for the

Mr. Wingfield.

other two cylinders, the cranks of which were at right-angles to the first pair, it was found that the maximum twist was only 1·2 of the mean turning-moment; a result which compared favourably with engines having their cranks 120° apart.

It had been assumed by the Authors, p. 61, that the indicated thrust at zero speed was a measure of the initial friction of the engines. He thought the initial thrust multiplied by the pitch of the propeller would be found to give a more accurate measure

Fig. 26.

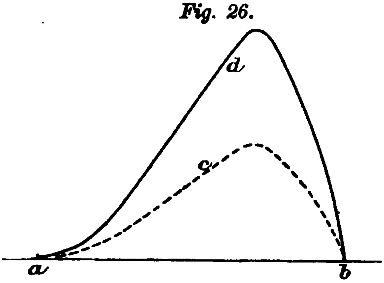


Fig. 28.

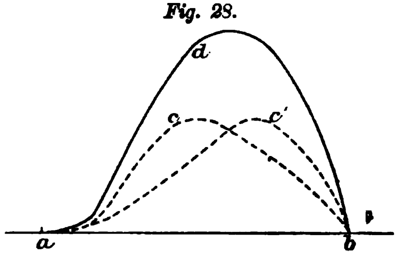
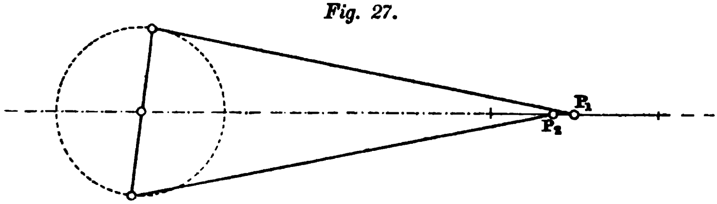


Fig. 27.



of the power wasted per revolution in friction.[1] Measured in this way, the friction per revolution of the "Speedy's" engines and shafting was 1·84 of that of the "Daring," although the latter had four cylinders and valves against three in the case of the "Speedy." If the thrust alone were considered to

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[1] It has been experimentally proved by Prof. R. H. Thurston (*Engineering*, vol. xlvii. p. 22, &c.) that the I.HP. wasted per revolution in overcoming friction is nearly constant at all speeds and loads, and that, contrary to what was at one time accepted, it is also nearly independent of the steam-pressure. That conclusion has since been confirmed by other experimenters, and the late Mr. Peter Willans has proved its correctness.

If the I.HP. wasted per revolution is thus constant, it can be represented by $\frac{t \times \text{pitch of propeller in feet}}{33{,}000}$, where t is a constant thrust corresponding with that given by Mr. Froude's diagram at zero speed. This is deduced from the equation for the indicated thrust-curve, which is

$$T = \frac{33{,}000 \times \text{I.HP.}}{\text{pitch in feet} \times \text{revolutions per minute}}.$$

Mr. Wingfield. represent friction, the ratio was $\frac{2800}{1750}$ or 1·6 only. He thought the thrust *per se*, which was a purely static pressure, could not be a measure of power wasted in friction, which was expressed in dynamical units. The adoption of horizontal bob-weights had been suggested by Mr. Beaumont. The use of such bob-weights had been, in the form of pendulums, fully considered when the engines had been designed. It had been decided, however, that they were unnecessary, and the engines had proved to be very free from vibration—so much so that vibration was scarcely perceptible in the engine-room, and the men in the boiler-rooms often did not know whether the engines were running or not. That was largely due to the causes given in the Paper, but partly, no doubt, to those which had been mentioned by Mr. Mark Robinson.

Prof. Boys. Prof. C. V. Boys expressed some hesitation in speaking before so many engineers on an engineering subject, and would not have ventured to do so had he not been one of the fortunate few who had been able to be present on the occasion when the "Daring" beat all previous records. It so happened that that took place on one of three consecutive days in which he was experiencing some modern methods of passing through the air at a high speed. One had been spent on a new racing bicycle; the second was that to which he had referred, and the third, or part of it, was spent in runs on Mr. Maxim's flying-machine. He would like to ask a question as to the limit of speed which was physically possible. If the skill of the mechanical engineer had been almost exhausted in producing a maximum of power with a minimum of weight, and that of the naval architect in producing a form of ship in which the resistance to passage through the water should be as small as possible; if further, as seemed to be the case, judging from the wave which was experienced, the amount of energy spent in producing waves in a vessel such as the "Daring" was not, after all, enormous compared with that occupied in overcoming skin-friction—anything that would reduce the skin-friction by even a very moderate amount might be a matter of great importance. An idea suggested was to pump air down the stem of the vessel and along the keel—not too far along the keel, as it was important that the air should not get into the propellors, but so far that the rising air should be entirely free from entering the rush of water which passed by them; then the question was, would the skin-friction be greater or less in rushing through the foam? Certainly *a priori* considerations, which he knew were of very little consequence, would have led him to believe that less skin-friction

would be experienced in driving a vessel through foam; and since only 1 HP. or so would be needed (taking a vessel of the size of the "Daring," and travelling at its speed) to send down enough air to coat the vessel with a layer, which, if continuous, would be $\frac{1}{4}$ inch in thickness; surely, if any advantage was to be gained by the use of that species of ball-bearing, then the power and the trouble involved would be slight in comparison with the gain, if that gain were any moderate percentage of the 4,000 HP. or 5,000 HP. which was developed in so small a ship. Prof. Boys.

Mr. BARNABY, in reply, said, in reference to Mr. Hutton's statement that it was impossible to lay the guns of the "Daring" with precision when going at full speed, and that it was necessary to stop the engines in order to take aim, he presumed that Mr. Hutton referred to the 12-pr. gun which was mounted upon the top of the conning-tower. By an error of judgment the top plate of the tower to which this somewhat heavy gun was attached had been made flat; and as the diameter of the base of the cone mounting was considerably less than that of the tower, the plate proved to be insufficiently rigid, and allowed the gun to shake with the motion of the ship. In the sister vessel, the "Decoy," and in all the later destroyers, the top of the tower was domed, and this simple alteration had remedied the defect. Mr. Barnaby had attended the gun-trials of the "Decoy" for the purpose of observing the behaviour of that gun, and he had seen all the guns laid and fired at speed, and so far as he knew no further trouble from the cause referred to had been experienced. Further particulars had been asked for by Mr. Yarrow as to the displacement of the "Daring" and the dimensions of her propellers; but he was sorry not to be able to give that information. He might state, however, that from the figures Mr. Yarrow had supplied, it was found that the performance of the "Hornet," as measured by the Admiralty displacement coefficient at 27·6 knots per hour, was between that of the "Daring" and the "Decoy," but that the later boats, the "Boxer" and the "Bruiser," which ran at a considerably higher speed, had given much higher coefficients. Particulars of the screws of the "Hornet" had been given by Mr. Yarrow, and Mr. Barnaby had found from those particulars that the negative pressure amounted to 6·15 lbs. per square inch. It was said in the Paper that cavitation appeared to become detrimental if a negative pressure of $6\frac{1}{4}$ lbs. per square inch was exceeded, so that the "Hornet's" screws gave results singularly near that figure, and showed that they were large enough for the power and speed obtained. It had been stated by Mr. Barnaby.

Mr. Barnaby. Mr. Seaton that he prided himself for having predicted the failure of the first screws of the "Daring," not only as to failure of speed, but as to the general result of working. He thought that before a prophet could take credit for a prediction, he must show that the prediction was previous to the event professed to be foretold. It so happened that the date of the conversation referred to was March 15th, 1894. The failure of the first screws of the "Daring," which Mr. Seaton said he foretold, took place in the months of January and February of that year, so that his statement was not quite a prediction. It was a matter of common knowledge in March among their competitors that there was a failure to obtain the speed with the screws of the "Daring." Mr. Seaton had stated that he had "mentioned these matters to show that the subject might be worked out without such an amount of scientific investigation as the Authors had favoured the Institution with." He could only say that the remarkable failure of the narrow-bladed screws came upon them as a surprise; and as the cause appeared to be novel and attributable solely to the high speed sought to be attained, they thought the results of the investigation they were led to make into the subject, and the conclusion they drew from them, might be of interest. Admiral FitzGerald did not see why the horizontal screen should not act, but would prefer the object to be attained by more flaring bows. It had been proposed to do that to some extent in the new destroyers, but it should be remembered that in long ships of that kind, flaring above water increased the bending-moments when in the trough of the wave, and he did not think it would suffice to keep the spray down. It would probably run up the flare of the bow until it arrived at the deck edge, and would then be blown on board, which was not the case if it met a horizontal screen. It was a most important point, as affecting the possibility of getting good practice with bow-guns at a high speed. If the chase made off to windward, it would put the pursuer at a great disadvantage in having to fire through the spray. It had also been said very properly by Admiral FitzGerald that the Navy would never be satisfied with any finality in speed. He did not say that the limit of speed had been reached, but expected a considerable increase over any that had yet been obtained. All he contended was that that increase of speed would probably be attained by some large sacrifice of power, because reduced efficiency of screw-propulsion seemed likely to attend any increase over what had been already effected.

Mr. Thornycroft. Mr. THORNYCROFT, in reply, said it was a mistake to suppose

that the boiler exhibited did not differ materially from that patented by Mr. Goldsworthy Gurney in 1827. One important feature which enabled the boiler to be put into a torpedo-boat with success, was that, instead of being surrounded by a fire-brick chamber, it consisted largely of walls of tubes. That formed a feature which protected the coal-bunkers from heat and enabled a large fire to be put near a considerable amount of combustible coal without danger. When fire-bricks were used, unless special means could be arranged to pass a current of air around the bricks, they became heated throughout, and the result was a temperature which was in danger of setting fire to the ship. He was glad to be able to say that the float-gear had worked exceedingly well. The feeding on the trial of the "Bruiser" quite recently was so perfect that for about three hours at full speed the feed was not touched, being regulated entirely automatically. It seemed merely to require that a man should watch, and that the pump in the engine-room should continue to supply the water which was distributed as required. The boiler represented in *Figs. 25*, consisted almost entirely of two rows of tubes having very narrow openings between them for the gases to pass through, which would not be suitable for the purpose in question. He might be permitted to say that it appeared to him that that boiler did not in any way forestall that described in the Paper. The questions raised by Mr. Mallock were of great interest, that of balancing engines being one which had recently occupied much attention. The disturbance which took place twice during the revolution, due to the obliquity of the connecting-rod, and consequently the greater acceleration during the upper part compared with the lower part of the revolution, due to the crank, was a matter which required attention. The point raised by Mr. Wingfield, the equality of the turning-moment, from what was equivalent to right-angled engines due to that obliquity, was an illustration of what might be a disadvantage in one case and a help in another. If there was a disadvantage due to obliquity, to some extent there was a gain in another respect; because really the stresses on the crank-shaft were reduced by the uniformity of the turning-moment. He would direct particular attention to the model exhibited by Mr. Mallock showing how the position of the nodes might be estimated, and also the period of vibration of a steamer. It might be true that, owing to the change of load, the nodes might vary somewhat in position, but in warships the distribution of the weights would vary little in any particular ship; and it was certainly a great point if the period of vibration

Mr. Thornycroft.

Mr. Thornycroft. could only be known before building a vessel. Great expense was often incurred in making new screw-propellers, because, on trying a vessel, it sometimes happened that the particular period at which the vessel vibrated coincided nearly with that of the period of revolution of the screw-propellers. He might be permitted to mention that costly modifications had been necessary in some of the largest and most expensive vessels running across the Atlantic. With regard to the rapid vibrations which took place in vessels, Mr. Mallock had stated that he had measured 1,500 in a minute. That appeared to be the fourth phase in a particular ship measured, where a vibration so small as $\frac{1}{100}$ inch was equivalent in acceleration to the force of gravity, so that objects would travel on a table and only touch it occasionally. There was one thing that unfortunately happened in ships and required special attention—that, although all the nodes of a ship might be known, and provision be made against vibration, still individual objects, such as binnacles and things standing, as it were, on levers, would synchronise with the engines. He thanked the members for the manner in which the Paper had been received, and acknowledged his indebtedness to the energetic assistance rendered by his staff in its preparation.

Correspondence.

Mr. Durley. Mr. R. J. Durley observed that, in the case of the "Daring," the indicated thrust at zero speed amounted to 1,750 lbs., the corresponding quantity for the "Speedy" being 2,800 lbs. These numbers were proportional to the frictional resistance of the main engines in the two cases; and the conclusion was drawn that the smaller loss from friction in the engines of the "Daring" was due to the fact that they were of the four-crank inclined type, as contrasted with the three-crank engines of the "Speedy." The two cases did not seem comparable, inasmuch as the engines of the "Speedy," although of practically the same I.HP. as those of the "Daring," were much larger and heavier, and were driven at a lower speed. It might therefore be expected that the total loss from friction would be less in a smaller and lighter engine, although the mechanical efficiency of the engine would not necessarily be higher. This view seemed to be corroborated by the value of the ratio $\frac{\text{indicated thrust at zero speed}}{\text{indicated thrust at full speed}}$ in the two

ships. From approximate figures he found the following values for this relation:— Mr. Durley.

Name.	Indicated Thrust at Zero Speed (T_0).	Indicated Thrust at Full Speed (T_1). $\frac{\text{I.HP.} \times 33,000}{S \times 101 \cdot 3}$	$\frac{T_0}{T_1}$
	Lbs.		
Speedy . . .	2,800	74,700 (approx. calc.)	0·0375
Daring . . .	1,750	45,000 (from curve)	0·0389
		53,000 (approx. calc.)	0·0330

The ratio $\frac{T_0}{T_1}$ giving roughly the power of the main engines wasted in friction, the close agreement of these figures would tend to show that there had been no great increase in mechanical efficiency from adopting the four-crank inclined type of engine.

He would be interested to know what, in the opinion of the Authors, was the reason for the great difference between the I.HP. per square foot of heating-surface of the boilers of the two ships in question, as shown in the following Table:—

Name.	I.HP. per Square Foot of Grate.	I.HP. per Ton of Boilers.	I.HP. per Square Foot of Heating-Surface.
Speedy	23·0	43·9	0·27
Daring	23·3	91·0	0·55

With nearly the same I.HP. per square foot of grate, the heating-surface in the case of the "Daring" was much more efficient.

Mr. B. F. Isherwood, Chief Engineer of the United States Navy, had always been of the opinion that torpedo-boats and torpedo-boat destroyers were too small for effective use except in smooth water and under particular circumstances unlikely to occur in the naval practice of great nations. Such vessels could be useful only in restricted littoral warfare. In the open sea they would prove useless and generally disastrous. They could not affect the result of any naval war, and it was probable that the money expended on them would produce better results if applied to the construction of sufficiently large sea-going vessels. The tendency from the beginning had been towards the enlargement of these vessels. That was inevitable, and would continue until they were merged into first-class gunboats or small corvettes capable of service at sea, Mr. Isherwood.

Mr. Isherwood. when they would cease to be torpedo-boats, although the name might survive.

Independently, however, of the value of such vessels as war-ships, lessons were to be learned from them in the dynamics of naval architecture which could not be derived from any other kind of vessel; because none were constructed of so small a weight per square foot of the vessel's horizontal projection, with so small a draught proportional to length, or with such high speed. The combination of these three factors enabled the torpedo-boat, at very high speeds, to rise in the water, so that the mean draught at the highest speed would be less than at lower speeds, less immersed midship section and less surface resistance to the water being thus exposed. The immersed form of the vessel should be modelled to attain this result, the bottom of the fore body being made an inclined plane up which the vessel was driven or lifted when its forward resistance was greater than its weight. The resistance increased in a much higher ratio than the square of the speed, but the weight remaining constant. These facts indicated that, in the case of vessels of small weight per square foot of horizontal projection, of great length relative to the draught, and attaining a very high speed, additional speed could be obtained without increase of power proportional to the ratio of power to speed at lower velocities. He inquired whether these factors, in the vessels described by the Authors, were of such values as to produce the lifting action. The answer could only be given as the result of experiment, but trials could easily be made with certainty. He suggested the following method: at each end of the vessel to be experimented upon, let there be provided a graduated plumbed rod and movable target, such as employed in levelling operations. On the shore, convenient to any course over which the vessel could be properly run—a course with sufficient depth and breadth of water to secure normal results—let there be mounted a levelling instrument, and let the vessel be placed before it, and let the targets on the rods be moved up or down until their centres coincided with the cross-hairs in the telescope of the instrument, the reading on the rod being noted. Then let the vessel be driven at various speeds up to the maximum, forward and backward before the instrument, and for each speed let the targets be moved as before until their centres again corresponded with the cross-hairs of the instrument, the reading on the rods at the centres of the targets being again noted. A comparison of the figures obtained from the rods when the vessel was in motion with those obtained when the vessel was at rest, would give

accurately the variations of the trim for each speed, and would also show how much the vessel had risen in the water at each speed, if at all. The speed of the vessel would be given by that of its screw at the moment the observations on the rods were taken, the number of revolutions being obtained from a mechanical counter for any convenient interval of time, say, five minutes to ten minutes. The length of the course for small vessels need not exceed a few hundred yards, and the means of the observations for both directions should be taken in order to neutralise the effect of the wind. There must be no appreciable rise or fall of the tide during an experiment. The speed of the vessel corresponding to the number of revolutions made by the screw per minute would be obtained from curves derived from a series of progressive trials. Such experiments should be made on all vessels where practicable, for the improvement of naval architecture and for the determination of the laws of the resistance of water to moving ship-formed solids partially immersed. In the case of small vessels like torpedo-boats, with which exhaustive and exact experiments could be conveniently made without great expense, it was well worth the while of builders, who constructed them by contract with guaranteed results, to make such experiments as would enable them to work with the greatest certainty and the least cost; for, although the desired results might finally be arrived at tentatively by trial and error on the large scale, such a process was always expensive and frequently unsuccessful. Reliance was to be placed only on instrumental measurements, opinions based on general observations unaided by such measurements being valueless. The importance of such considerations might be measured by the fact stated by the Authors that the guaranteed speed of some torpedo-boat catchers had been, on their trials, exceeded by between 1 knot and 2 knots, which showed that their designers were not sure, as regarded dimensions and power, of what would produce the required results, and therefore had to secure them by the use of an excess of material and labour. The cost of producing the additional and uncompensated speed would probably have paid for many experiments to enable a closer approximation to be made. Mr. Isherwood.

It was stated in the Paper that all the screws employed had expanding pitches from fore to aft, and that their slips had been calculated from their mean pitch. This method was erroneous; the slip of a screw with fore-and-aft expanding pitch should be calculated from the aft or final pitch. The true slip of a screw was the speed with which the water left it relatively to that of the

Mr. Isherwood. vessel, the former being determined by the final pitch alone. The thrust of a screw was always much less than that calculated from the mean pressure on the indicator-diagram by reducing the pressure on the crankpin in the ratio of the length of a double stroke of the piston to the length of the pitch. The true thrust had no fixed relation to the imaginary "indicator thrust," and the latter had no value for any purpose; whatever deductions might be drawn from it were necessarily erroneous. It was also stated (p. 59) that the heeling outwards of a vessel turning in a circle was due to centrifugal force. When a vessel turned, its centre of gravity only described the circle; its keel lay across the circumference, with the stem inside and the sternpost outside it. The movement in the circle was caused solely by the simultaneous forward movement of the vessel in the line of its keel given by its propeller, and its rotation on its centre of gravity given by the rudder. The heeling of a vessel turning in a circle was due entirely to the vertical distance between the horizontal planes in which lay the centre of pressure of the rudder and the centre of lateral resistance of the vessel. The direction of heel was outwards or inwards accordingly as the former was above or below the latter plane; and its amount, other things being equal, was proportional to the distance between the two planes. If the planes coincided, there would be no heel, however great the speed of the vessel. The heeling action was in no way due to centrifugal force. When the centre of gravity of a vessel described a circle, the continuous deflection of the keel from the tangents of the circle was not caused by the action of a central force, as in the case of the gravitation of the planets, or in that of a stone whirled in a sling, but was caused solely by the action of the rudder.

Mr. Normand. Mr. J. A. Normand remarked that the experiments on the French torpedo-boat 153, to which the Authors alluded at the end of the Paper, had shown that the diameter, blade-area and immersion of screw were more than sufficient to avoid the rupture of the propulsive column of water when under weigh in smooth water. He believed that higher speeds could have been attained with screws of less resistance, and with the axis of the shaft more nearly parallel to the flow of water at the stern. But the screw had been so proportioned and immersed as to prevent rupture in a heavy sea, with the increase of displacement which could not be avoided in service, whatever might be the weights on board during the trials; and to this was due the remarkably small loss of speed experienced in service by boats of this type. The same had previously been observed in the comparative trials in Spain and

Russia, the Normand boats then tried having very large screws. Mr. Normand.
The advantage thus gained was probably more important than that to be derived from a very small draught of water. According to the Authors "the speed of vessels has now approached within measurable distance of that at which propulsion by screws depending upon the reaction of water, becomes inefficient." He could not see reason for a limitation to the speed, provided the resistance of the screws augmented in the same rate as the resistance of the hull with the increase of speed.

THE AUTHORS, in reply to the Correspondence, observed that The Authors.
Mr. Durley had advanced the view that in two engines of the same indicated horse-power, the loss from friction (by which term his calculations showed he meant that portion of the indicated thrust which was neutralized by friction) might be expected to be less in the smaller engine, although its mechanical efficiency would not necessarily be higher. Was not this equivalent to saying that if from two equal quantities unequal amounts were deducted, the remainder would not necessarily be greater in the case where the least quantity had been subtracted? In calculating indicated thrust, the Authors had followed the method employed by the late Mr. Froude, who took it as $\frac{\text{I.HP.} \times 33{,}000}{\text{pitch} \times \text{number of revolutions}}$. Since Mr. Durley's third column was calculated in a different way it could not be compared with the second column. When calculated in the manner employed in the Paper, the thrust at full speed was 57,300 lbs. for the "Speedy" and 44,400 lbs. for the "Daring," giving efficiencies of $\frac{44{,}400 - 1{,}750}{44{,}400} \times 100 = 96 \cdot 9$ and $\frac{57{,}300 - 2{,}800}{57{,}300} \times 100 = 91 \cdot 6$ for those vessels respectively. The "Daring" was thus 5·3 per cent. more efficient than the "Speedy." It was a matter of common experience that, in two engines of similar design, the larger one was the more efficient; so that to have obtained a higher efficiency with the smaller engine, pointed, in the Authors' opinion, to a considerable improvement in the "Daring" design as compared with that of the "Speedy." In reply to Mr. Durley's question as to the reason why the indicated horse-power obtained per square foot of heating-surface was so much greater in the "Daring" than in the "Speedy," the former was forced much harder, that is, more coal was burned per foot of heating-surface. As the grate-area was much larger in relation to the heating-surface in the boilers of the "Daring" than in those of the "Speedy," the coal burned per square foot of grate-area did not differ greatly in the two cases.

The Authors. In reply to Mr. Isherwood, the Authors did not desire to discuss the value of torpedo-boats either for littoral warfare or for use in the open sea. The question as to whether or not money expended on them would produce better results if applied to the construction of large sea-going vessels, lay outside the scope of the Paper. A large number of torpedo-boats were in existence, and an efficient vessel was required for their destruction. The first-class gun-boats and small corvettes preferred by Mr. Isherwood existed also in numbers in the British Navy and did good service. The "destroyer" did not supplant them but supplemented them, and its superior speed enabled it to overhaul the torpedo-boat in any weather.

Although it might be possible to get small, heavily-powered, specially-constructed vessels to lift themselves in the water in the manner described by Mr. Isherwood, the Authors did not think any action of the sort took place in the destroyers, and doubted whether such an experiment as that suggested by him—even if the difficulties of making it could be overcome—would establish the fact of their lifting in the water. It would merely show a rise or fall as compared with still water; but the whole surface of the water in the neighbourhood of the vessel was affected by its passage at high speed; and the vessel might be borne up on the crest of a wave travelling with it, or even be depressed by lying in a trough, without the occurrence of any change in mean draught.

The Authors were aware that the true slip of an expanding-pitch propeller was not correctly obtained from the mean of the pitches of the forward and after edges, and they had been careful to point out that the effective pitch was greater than the mean thus obtained. In the screws of the "Daring," the pitch did not increase uniformly from forward to aft, nor was it the same for the whole of the after edge; and it was by no means a simple matter to determine the real pitch and slip of a screw so constructed. They had considered that for their purpose the method employed was the best. The objections of Mr. Isherwood to the use of "indicated thrust" were not shared by the Authors. It had been employed by the late Mr. Froude as a means of comparing the initial friction of engines, and for this purpose it appeared to the Authors to be useful. Of course, it was always greater than the true thrust. It might be said to represent the true thrust produced by a frictionless engine and propeller, the propeller moreover being so placed as to produce no augmentation of resistance.

They could not agree with Mr. Isherwood's explanation of the

behaviour of a vessel when turning a circle. The Authors, on the contrary, believed that a vessel heeled outwards in turning owing to centrifugal force. When a ship had acquired momentum in a straight line, and was more or less suddenly constrained to move in a circle, the momentum acting through the centre of gravity of the whole body tended to cause the centre of gravity to continue to move in a straight line tangential to the circle in which the ship was constrained to move. It was prevented from doing so by the side-wise resistance of the ship, which had been forced by the rudder to assume a position oblique to her former direction. This side-wise resistance acted nearly through the centre of area of the immersed vertical longitudinal section, which was always below the centre of gravity, and a heeling-couple was thus produced. The higher the ship's centre of gravity, the more would she tend to heel out, due to the centrifugal tendency of the centre of gravity. If the rudders were placed low, the pressure upon them tended to counteract the outward heel, and would sometimes, as in the "Daring," force the vessel to heel inwards. The Authors.

The Authors quite agreed with Mr. Normand that it was wise when possible to make the screws somewhat larger than was necessary for smooth-water trials at designed draughts in order to avoid excessive slip in rough weather and when deeply loaded [1]; but it sometimes happened that the conditions of trial were so onerous that no sacrifice of efficiency under these conditions could be accepted. They also agreed with him that no limitation to the efficient performance of the screw need be anticipated, provided the resistance of the screw augmented at the same rate as the resistance of the hull with increase of speed; but they found in the "Daring" that the resistance of the screw, or in other words, the thrust with a given slip-ratio, did not so augment.

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9 April, 1895.

SIR BENJAMIN BAKER, K.C.M.G., Vice-President, in the Chair.

The discussion upon the Paper on "Torpedo-Boat Destroyers" occupied the evening.

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[1] Minutes of Proceedings Inst. C.E., vol. cii., p. 81.

14 May, 1895.

WILLIAM HENRY PREECE, C.B., Vice-President, in the Chair.

In accordance with the provisions of Section VI, Clause 2, of the By-Laws, the Council presented the list of persons nominated as suitable for the offices of President, Vice-Presidents and other Members of Council for the ensuing year.

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21 May, 1895.

WILLIAM HENRY PREECE, C.B., Vice-President, in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Member.

William Henry Cole.
Walter Edmund Cook.
William Julius Mirrlees, B.Sc.
James Smith Mollison.
Oliver Claude Robson.
Edward Brownfield Wain.
Alfred Edward White.

And that the following Candidates had been admitted as

Students.

Walter Lacy Allcroft.
Taggart Aston.
Charles Orr Campbell, B.E.
Gaspard Robert de Mussenden Carey.
Jesse Edward Chapman.
Louis Whitfoot Clarke.
William Harold Arthur Court.
Alexander Gratitude Craig, B.Sc.
Alfred Arthur Davis.
Clement Frederick Davis, B.A.
George Crosbie Dawson.
Robert Manning Dowson.
Haines Breebaart Ede.
Arthur Grimshaw.
John Inglis, B.Sc.
James Gray Mathieson.
Allan Macrae Moir.
Harry Scott Morrison.
John Leslie Mowbray.
James Just Niven.
Henry John Rofe, B.A.
Leslie Roseveare.
Charles William Scott.
Benjamin Thomas Stubbs.
John Taylor.
Edward Lloyd Williams.
Hamilton Arnison Woods.

The Candidates balloted for and duly elected were: as

Honorary Members.

OCTAVE CHANUTE.
HENRI SCHNEIDER.

Members.

HARRY VICTOR SAMPSON BAKER.
RAWLINSON TENNANT BAYLISS.
GEORGE HUMFRESS.
EMANUEL ALOIS ZIFFER.

Associate Members.

FRANK JOSEPH AGABEG.
WILLIAM BANKS.
HENRY KYNASTON BLAKE.
HENRY LANE BROWN.
MATTHEW TAYLOR BROWN, B.Sc.
GERARD MACLEAY BROWNE.
ROBERT ARTHUR BRUCE.
EDMUND BURROWS.
FREDERIC EDWARD THEODORE COBB.
REGINALD HARRATT CROMPTON, Stud. Inst. C.E.
HENRY MANGLES DENHAM.
ARTHUR MONTEFIORE WIRE EASTEN.
HERBERT FRANCIS EDWARDS.
HARRY GLEN FINLAISON.
JAMES FORGIE.
JAMES FRASER.
WILLIAM WILLIS GALE.
BERNARD GODFREY, Stud. Inst. C.E.
LOUIS GREENE, Stud. Inst. C.E.
JOSEPH HAWKSLEY.
JOSEPH HOPE.
WILLIAM INGHAM.
EDMUND WILLIAM JANSON, M.A.
CHARLES WILLIAM JENKINS.
WILLIAM ARTHUR BAIRD LAING.
WILLIAM ROBERT MANNING.
BIANOR SILVANO DE MENDONCA
WILLIAM JAMES MILLNER.
JOSEPH RUSHWORTH.
JOEL SETTLE.
JOSEPH SHEPHERD.
SOPHUS SIMMELKJÆR.
CHARLES EDWARD SIMPSON.
THOMAS WILLIAM LORAINE SPENCER.
SIDNEY STALLARD, Stud. Inst. C.E.
WILLIAM GEORGE WALKER.
BERTRAM BRAUND WALLER.
GEORGE BLISS WINTER.

ANNUAL GENERAL MEETING.

28 May, 1895.

SIR ROBERT RAWLINSON, K.C.B., President, in the Chair.

The Notice convening the Meeting was taken as read, as well as the Minutes of the Annual General Meeting of the 29th of May, 1894, which the President was authorized to sign.

It was moved, seconded, and resolved,—That Messrs. J. Angus, G. Chatterton, W. Santo Crimp, E. R. Dolby, A. C. Hurtzig, W. I. Last, C. S. T. Molecey, W. F. Pettigrew, W. S. Rendel, A. W. Szlumper, T. Frame Thomson, John J. Webster, and L. S. Zachariasen, be requested to act as Scrutineers for the election of a President, of four Vice-Presidents, and of fifteen Other Members of Council for the ensuing year; and that, in order to facilitate their labours, the Ballot-papers be removed for examination at intervals during the time the election remained open.

The Ballot having been declared open at five minutes past eight, the Report of the Council upon the Proceedings of the Institution during the Session 1894–95 (p. 108) was read, the Statement of Accounts being taken as read. After discussion it was

Resolved,—That the Report of the Council be received and approved, and that it be printed in the "Minutes of Proceedings."

Resolved,—That the incoming Council be requested to take into consideration the matter of printing in the Balloting-list the names of the existing Council in a distinguishing type, and to adopt such steps as may be necessary to give effect to this.

Resolved,—That this Meeting notes, with satisfaction, that the Council has considered the question of admitting non-resident members to participation in the election of the Council, and requests it to further consider the matter.

The Ballot was then declared to be closed, having been open more than an hour.

Resolved,—That the thanks of the Institution be tendered to the Vice-Presidents and other Members of Council for the assistance they had rendered in promoting its objects.

Sir Benjamin Baker, the senior Vice-President, replied on behalf of himself and his colleagues.

Resolved,—That the members present at this meeting desire, on behalf of themselves and others, to place on record their high appreciation of the services rendered to the Institution by Sir Robert Rawlinson, President, during his year of office.

Sir Robert Rawlinson, President, returned thanks.

Resolved,—That Messrs. Francis Fox and W. T. Douglass be thanked for the time and trouble they had bestowed in auditing the Accounts for the past financial year; and that Messrs. W. T. Douglass and A. C. Hurtzig be requested to act as Auditors for the ensuing twelve months.

The Scrutineers then reported the election of:—

President.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S.

Vice-Presidents.

John Wolfe Barry, C.B., F.R.S.
William Henry Preece, C.B., F.R.S.
Sir Douglas Fox.
James Mansergh.

Other Members of Council.

William Anderson, D.C.L., F.R.S.
Alexander Richardson Binnie.
William Robert Galbraith.
James Henry Greathead.
J. C. Hawkshaw, M.A.
Charles Hawksley.
John Hopkinson, Jun., M.A., D.Sc., Wh.Sc., F.R.S.
Alexander Blackie William Kennedy, LL.D., F.R.S.
Sir Guilford L. Molesworth, K.C.I.E.
Captain Sir Andrew Noble, K.C.B., F.R.S., late R.A.
Sir Edward James Reed, K.C.B., F.R.S., M.P.
William Shelford.
Francis William Webb.
Sir William Henry White, K.C.B., LL.D., F.R.S.
Sir Edward Leader Williams.

Resolved,—That the thanks of the meeting be given to the Scrutineers, and that the Ballot-Papers be destroyed.

REPORT OF THE COUNCIL, Session 1894–95.

In presenting to this Annual General Meeting a statement of the present condition of the Institution, the Council performs the last act of the duties imposed upon it when it assumed office a year ago.

The Roll.

The changes which have taken place during the twelve months ending the 30th of March, 1895, are fully detailed in the accompanying tabular statement. The elections included 29 Members, 286 Associate Members and 5 Associates, while the names of 2 Members and 3 Associate Members were restored to the register—a total of 325 to the credit side of the roll. The deaths, resignations and erasures amounted to 170, an unusually large number. The net increase, therefore, was 155, or at the rate of 2$\frac{4}{7}$ per cent. per annum. It is satisfactory to note that the Students continue to form a valuable recruiting ground for the Institution, the number elected to the Associate Member class during the

—	April 1, 1893, to March 31, 1894.						April 2, 1894, to March 30, 1895.					
	Honorary Members.	Members.	Associate Members.	Associates.	Totals.		Honorary Members.	Members.	Associate Members.	Associates.	Totals.	
Numbers at commencement	15	1,810	3,377	376		5,578	20	1,832	3,557	357		5,766
Transferred to Members	..	65	65	..			..	58	58	..		
Transferred to Associate Members	..	..	1	1			..	..	..	..		
Elections	6	20	305	3	337		..	29	286	5	325	
Restored to Register	..	..	3	..			..	2	3	..		
Elected Honorary Member	..	..	..	1			..	..	..	..		
Deaths	1	45	24	12	149		3	47	36	3		
Resignations	..	13	21	5			..	6	26	2	170	
Erased	..	5	19	3	—	188	..	6	39	2	—	155
Numbers at termination	20	1,832	3,557	357		5,766	17	1,862	3,687	355		5,921

twelve months under review being 94. The total number of members on the register on the 30th of March, 1895, was 5,921, as against 5,766 on the 31st of March, 1894.

Amongst the deceases of the year have been three distinguished Honorary Members—Carnot, von Helmholtz and de Lesseps; an esteemed Past-President—Alfred Giles; and Edwin Clark—Robert Stephenson's chief representative on the construction of the iron-work of the Britannia and Conway bridges.

The deceases have been:—

Honorary Members.—Marie François Sadi Carnot (President of the French Republic); Hermann Ludwig Ferdinand von Helmholtz; and *Sir* Ferdinand de Lesseps, G.C.S.I., LL.D.

Members.—William Barrington; Joseph Henry Brady; William Brentnall; Robert Pearson Brereton; Thomas Fletcher Chappé (de Leonval); William Buchan Christie; John Flèming Churchill; Edwin Clark; Robert Crichton; James Cross; Henry Faija; Patrick John Flynn; George Garnett; Alfred Giles (*Past-President*); John Maitland Grant; John Harrison; *Lt.-Col.* William Haywood; John Hill; Arthur Jacob, B.A.; Thomas Masterman Hardy Johnston; Robert Jones; Henry Kemp; Thomas Stuart Kennedy; Charles Benjamin Knorpp; Henry Christopher Digges La Touche; William Richard Le Fanu; Edward John Lloyd; James Braddon McCallum; Antonio Gomes de Mattos; James Murdoch Napier; William Henry Edward Napier; David Phillips; Robert Piercy; Joseph Quick; John Richard Ravenhill; Alfred George Woodward Reid, C.M.G.; James Reid; Edward Reynolds; Thomas Manson Rymer-Jones; John Chaloner Smith; Allan Duncan Stewart; Joseph Frank Strong; James Page Symes; John Lewis Felix Target; Joseph Tomlinson; William Vawdrey; and John Evelyn Williams.

Associate Members.—Robert Barnes; William Henry Brace; John Williams Brewer; William Joseph Brown; John Burgess; Charles Burton; George Stephenson Campbell; Octavus Deacon Clark; George H. Cole-Baker, B.A.; George Eraut; John Dunn Ferguson; Alfred Forrest; James French; Tom Gledhill; Charles Cressy Horsley; David Charles Jones; Edwin Davenport Latham; William MacGlashan; John Waddington Mann; James Archibald Maughan; Frederick William Maunsell, B.A.; William Henry Morrow; Karl Emil Nabholz; Albert Woodward Parry; William Monro Pearse; Alfred Coveney Priestley; Charles Henry Rogers; Giorgio C. Schinas; John Parry Scotland; Charles Henry Sparkes; Harry Laurie Stannard; John Henry Strachan; Charles Willman; William Adolphe Worsoe; Harry Wreathall; and Cesare Zanetti.

Associates.—Elim Henry D'Avigdor; William Rosser; and William Topley, F.R.S.

The following resignations have been accepted:—

Members.—Daniel Manders Beere; William Wood Culcheth; William John Greer; Henry Beecroft Harvey; Rupert Turberville Smith; and John William Mitton Watson.

Associate Members.—James Trembath Boase; John Buchan; Charles Campbell; Thomas Alfred Colfox; Charles Cowan; John Hyde Edwards; William Cooke Faber, M.A.; James Staats Forbes, jun.; John Ellard Gore; Robert

Harris Morris Green; William Henry Mackenzie Green; James Grimes; Thomas William Jeffcock; Henry Cecil Jones; Frederick Nix Latham; Christopher John Nevitt; Frederick Henry Rowling; Walter Douglas Seaton; Arthur John Simpson; Tom Graves Smith; Henry Charles Anderson Timins; Thomas Herman Tyndall; Samuel Kingston Vickery; William Stanley Whitworth; Hugh Edward Whytehead; and Arthur Edwin Wild.

Associates.—Henry Hughes and Edward MacFarlane.

Admission of Students.

The conditions under which admission to the Student Class is gained have continued to exercise the earnest attention of the Council. Although the Students are neither members of the Body Corporate, nor invested with any of the rights appertaining thereto, the privileges to which they are admitted are very considerable, and the importance of this class in regard to the training of engineers, can hardly be overstated. Whilst avoiding any attempt to direct or control the technical study in which students are expected to engage, though affording them every facility for professional improvement, the Council has for some years past insisted upon the possession, by all candidates for admission into this class, of a competent knowledge of the subjects of a sound general education. The regulations relating to the preliminary education of Students, revised from time to time as circumstances dictate, are strictly enforced; and it is satisfactory to find that the number of applicants failing to comply with the requirements is comparatively small.

For the first time since the Council introduced the higher educational qualification of candidates for admission as Students, it is able to report an effective increase in the roll at the end of twelve months' working. On the 31st of March, 1894, the number on the books was 791. During the year 212 candidates were admitted Students and 1 name was restored to the register, while 188 ceased to belong to the class. The net increase was therefore 25, making on the 30th of March, 1895, a total of 816. Of the 188 whose names disappeared from the list of Students, exactly one-half were elected into the Associate Member class. Complete details of these changes are given in the Table on following page.

The class having been formed in 1867, it is not surprising to find that only 191 of the present Members have belonged to it; but it is satisfactory to observe that 1,529 of the Associate Members now on the roll were formerly Students.

Whilst the advantages accruing to Students from early association with the work of the Institution are very great, that connec-

tion is of important service to the entire body, ensuring as it does that the whole training and career of such persons elected into the Corporation readily admit of the fullest scrutiny.

STUDENTS.

1893–94.			
April 1, 1893 . . .			819
Admitted during the year		170	
Elected Associate Members	100		
Resigned	22		
Deceased	1		
Erased	75		
		198	
			-28
March 31, 1894 . .			791

1894–95.			
April 1, 1894 . . .			791
Admitted during the year	212		
Restored to Register .	1		
		213	
Elected Associate Members	94		
Resigned	14		
Deceased	2		
Erased	78		
		188	
			25
March 31, 1895 . .			816

FINANCE.

The Statement of Accounts (see p. 120), the accuracy of which is vouched for by the Auditors, presents some special features involved by the expenditure on the building now in course of construction. It is not possible, therefore, nor would it be advantageous, to draw comparisons between the account of this year and that of last year, so that the present statement must be accepted on its own merits and on its own showing.

The balance on the 2nd of April, 1894, was £10,677 12*s.* 1*d.* The receipts for the year have been as follows:—on Income account, £20,970 3*s.* 10*d.*, including £16,940 4*s.* 6*d.* from subscriptions and £2,288 14*s.* 2*d.* from dividends; on Capital account, £8,933 1*s.* 2*d.*, of which £5,212 9*s.* 2*d.* represents the proceeds of the sale of £4,667 London and North Western Railway 3 per cent. Debenture Stock, realised towards the cost of the new building; and £445 13*s.* 2*d.* on Trust-Funds account—together, £30,348 18*s.* 2*d.* On the other side of the account the following items may be noted:—General Expenditure, £18,385 10*s.* 11*d.*, including £7,970 19*s.* 11*d.* for four volumes of the Minutes of Proceedings, £100 on account of the Subject-Index to Vols. LIX.–CXVIII., £1,326 15*s.* 8*d.* on account of the revision and printing of the Library Catalogue, and £173 2*s.* 3*d.* Succession Duty on the Palmer Bequest, special mention of which is made later

in the report; Capital Expenditure, £7,130 8*s.* 11*d.*, of which £5,407 15*s.* 0*d.* has been spent directly on the new building, while the remainder has been absorbed by the rent, etc., of temporary premises, by the cost of removing, fitting up library and warehousing, and by legal charges; and Trust-Funds Expenditure, £492 9*s.* 6*d.*—together £26,008 9*s.* 4*d.* The balance on the 30th of March, 1895, was therefore £15,018 0*s.* 11*d.*, of which £14,000 is on deposit with the bankers at the current rate of interest, to meet anticipated early payments on account of the new building.

During the year the nominal value of the holding in Lancashire and Yorkshire Railway Debenture Stock has been increased from £6,000 to £8,000 by its conversion from 4 to 3 per cent. The investments are now as follows:—On Institution account, £70,000 in Consols, Metropolitan Board of Works Stock and Railway Debenture Stock; £40,000, the cost of the freeholds in Great George Street; and £5,400, the nominal value of the Whitworth legacy: on trust-funds account, £16,987 2*s.* 4*d.*, including the Palmer bequest of £1,381 1*s.* 6*d.*, which has reverted this year—together, £132,387 2*s.* 4*d.*

Palmer Scholarship.

In the Report of the 19th of December, 1882, it was stated that the Council had accepted in trust, from the widow of Henry Robinson Palmer, a former Vice-President of the Institution, a bequest of £1,500 (less legacy duty and subject to a life interest), to be devoted to found a Scholarship at Cambridge University, tenable by the son of a Civil Engineer—the holder to be in need of such assistance and to be nominated by the Council. On the death in July last of Mr. John Bailey Surgey, who held the life interest referred to, the Institution came into possession of the sum of £1,381 1*s.* 6*d.* Metropolitan Board of Works Three Per Cent. Stock, the first dividend upon which was received in November. The proceeds may be estimated at about £40 per annum. In order that the fund might not be depreciated to an extent incompatible with giving proper effect to the generous testatrix's object, the Council decided that the Institution should discharge the claim for Succession Duty (£173 2*s.* 3*d.*).

Session and Meetings.

Owing to the necessity, hereafter referred to, of delivering the meeting-room to the Contractors in April, the Institution met for

the reading and discussion of Papers on only twenty evenings during the past session. Exclusive of the President's Address, fourteen original communications were read and discussed, but the exceptional interest evinced in the debates on some of the subjects brought forward has reduced the falling off that might have been anticipated in the amount of material available for Sect. I of each of the customary four volumes of Minutes of Proceedings.

In noticing briefly the Papers read at these meetings it is convenient to adopt an arrangement which has the advantage of reminding members of the catholicity of this Institution. So long as it can be shown that a memoir relates to matter germane to the profession of a Civil Engineer—using the term in its widest sense—each Author's contribution is carefully considered and accepted or rejected purely on its merits. It has been the custom to adhere, in classifying the different branches of the profession, to the order given in Thomas Tredgold's classical definition of the art of the engineer, which assigns the first place to "works for facilitating and improving internal communications." Adopting this order in respect of the Papers read last session, three memoirs, "The St. Gothard Mountain Railway and the Stanzerhorn Cable-railway" by Mr. Sigvard Johnson Berg, "The Monistrol-Montserrat Rack-railway," by Mr. Alfred Collett, and "The Usui Mountain Railway, Japan," by Mr. C. A. W. Pownall, have first to be mentioned. These contributions were grouped together so as to avoid the same ground being traversed more than once in the discussion. Mr. Berg's communication was designed to direct attention to two notable Swiss Railways, both mountain lines, but differing from one another in nearly every essential, the St. Gothard Railway being a most important link in a long chain of international communication accommodating the heaviest class of traffic, whereas the cable-way up the Stanzerhorn is merely designed to provide for tourists a means of ascending the mountain from which it takes its name. The most noticeable feature of the Stanzerhorn cable-railway is its division into three sections arranged to work independently of each other, so as to avoid the use of very long cables, while obtaining an easier route than would otherwise have been practicable. The Paper on the Monistrol-Montserrat Rack-railway, by Mr. Collett, described another tourist line, worked on a different system and affording a favourable opportunity for the employment of the Abt bar-rack. Mr. Pownall's Paper on the Usui Mountain Railway differed again from the others, in that it referred to a section of main lines in which the combined rack-and-adhesion system was

adopted. The first two communications of this group contained valuable appendixes, which, largely added to by those who contributed to the correspondence, give the leading dimensions, etc. of many mountain railways in various parts of the world. A long and animated debate followed the reading of these Papers, which, with the discussion and correspondence, occupy 150 pages, and form a notable contribution to the solution of one of the great problems of the day, namely, the extension of railway facilities to remote localities, difficult of access, where great natural obstacles have to be surmounted. The accounts of "The Kidderpur Docks, Calcutta," and of the "Movement of the Walls of the Kidderpur Docks," by Mr. W. D. Bruce and Mr. J. H. Apjohn respectively, were of great interest and importance to engineers concerned with retaining-walls.

In the department of mechanical engineering, Mr. Albert J. Durston's Communication on the "Machinery of Warships" was of importance beyond the ordinary limits of professional interest, on account of its referring to that which engineers, at least, would maintain to be the most vital features of the ships which constitute our first line of national defence. A new departure which has attracted unusual attention was the announcement of the definitive adoption on a large scale of water-tube boilers for fast cruisers. Mr. W. H. Fowler's Paper on "Boiler-Explosions" referred to a subject which had not been specially considered at the Institution for many years. As might be expected in a case affording such scope for difference of opinion, the Author's views gave rise to considerable criticism. Although not considered at the same time, the memoirs by Mr. John Richardson and Mr. Henry Davey on "The Regulation of Steam-Engines" and "Steam-Engine Economy" respectively, referred to subjects so closely allied that they may be grouped together in this Report. Mr. Richardson, while fully acknowledging the excellence of some types of ball-governor, advocated the claims of shaft-governors as the more scientific and accurate device for securing economy of steam. Approaching the same object from a different and more general point of view, Mr. Davey advanced a plea on behalf of the Cornish engine, the efficiency of which he maintained had never been exceeded. Recent progress in efficiency was considered to be due to the use of steam of higher pressure than was compatible with the ordinary Cornish cycle, and not to any defect of the latter. Mr. Davey also maintained that modern improvements in steam-engines were in the main due to the unceasing experiments carried on by manufacturers rather than to theoretical speculations.

In mining engineering, a Paper by Mr. E. B. Wain on "Colliery Surface-Works" was read. In this the Author gave a detailed description of the surface-arrangement of a typical colliery in Staffordshire, as a text from which to emphasize the vast importance of adopting machinery of the most improved type, so as to enable colliery-owners to keep down the ratio of working expenses to output, and so to cope with the increasing responsibilities to which legislation in the interests of the miners renders such proprietors liable.

In metallurgy, a communication by Messrs. Charles Butters and Edgar Smart on "Plant for the Extraction of Gold by the Cyanide Process," was dealt with. This was a general description of the process, with a detailed account of the engineering features of the plant necessary for its application.

The rapidity with which electricity, in its practical applications, is entering into every department of the engineer's work, was illustrated in the case of two Papers which, for convenience of discussion, were bracketed together, as referring to the transmission of power by electricity. Of these, "Electrical Haulage at Earnock Colliery," by Mr. Robert Robertson, illustrates the application of electricity to mining, while Mr. Robert Hay's Paper on "Water-Power applied by Electricity to Gold-Dredging" presents an instance of the adaptability of that medium to the requirements of the metallurgist. The interest in these Papers mainly centred in the electrical installations adopted by the Authors to perform operations which previously depended upon less convenient mechanical appliances.

The last Paper of the Session dealt with naval architecture—the monograph on "Torpedo-Boat Destroyers," by Messrs. John I. Thornycroft and S. W. Barnaby, being probably appropriately so classed, although it may be difficult to determine whether the naval architect or the mechanical engineer performs the more important functions in the production of a modern fighting ship. Messrs. Thornycroft and Barnaby's Paper will be so fresh in the recollection of the members that it is unnecessary to recall it except to mention that it was most effectively illustrated by transparent photographs projected on a screen by means of the oxyhydrogen light.

For the Papers comprising Section I of the Minutes of Proceedings, awards have been made to Messrs. A. J. Durston, R.N., J. I. Thornycroft, S. W. Barnaby, W. Duff Bruce, S. J. Berg, Charles Butters, Edgar Smart, and John Richardson.

This enumeration only refers to the Papers read and discussed

at the meetings, but since the last Report a large number of communications of an exceedingly varied nature has been selected for printing in Section II. As the majority of these have already been circulated in the pamphlet form, it will suffice to refer to the sense of the value of some of them entertained by the Council, as indicated by the award of premiums to Messrs. Archibald Sharp, J. A. Griffiths, Alfred J. Hill, Oscar Guttmann, C. A. Leibbrand, Adam Scott, David Cunningham, and to the representatives of the late Henry Gill.

Although not part of the original work of the Institution, the Abstracts of Papers in Foreign Transactions and Periodicals which form Section III of the Proceedings continue to be highly appreciated, especially by members residing abroad. So frequently are applications made to the Institution for detailed particulars of processes or apparatus referred to in these Abstracts, that there is no room for doubt that they constitute a very valuable feature of the publication. It may be mentioned that, although brief summaries only of the Papers are given, the object being that the reader should consult the originals for details, the Institution undertakes to produce such originals whenever called for, and spares no pains to elicit fuller information from the Authors of the articles abstracted should it be demanded by any member.

Students' Meetings and Visits to Works.

The Supplemental Meetings held during the Session have been eleven in number. The maximum attendance was 54, the average, however, being only 36.

Several Papers of considerable merit were read and discussed at these Meetings, and Miller Prizes have been awarded to Mr. W. G. Wales for his Paper on "Caissons for Closing Lock- and Dock-Entrances," to Mr. S. H. Barraclough for the Paper, contributed jointly with Mr. L. S. Marks, on "Some Experiments on the Heat-Losses to the Cylinder-Walls of a Steam-Engine," and to Mr. E. E. Matheson for his description of "Timbering in the Ampthill Second Tunnel." These communications, together with that by Mr. Stewart, "Glasgow District Subway," read at a meeting of the Glasgow Association of Students, have been deemed worthy of publication in abstract in the Proceedings.

Owing to the slight support given of late by the Students to Visits to Engineering Works, it has been thought proper to reduce the number of such inspections considerably. At the four visits

paid during the Session the average attendance was 22, only 12 Students being present on one occasion—a circumstance which is neither encouraging to the Council nor creditable to the Student Class.

The reports received from Manchester, Glasgow, Birmingham, Newcastle-on-Tyne and Leeds, show that the Associations of Students at those centres maintain the promise of previous years. In assisting the professional studies of those attached to them, as well as in promoting union among them, these local associations are undoubtedly useful in the several districts and are a source of strength to the Institution.

For Papers read before local Associations, and submitted in competition for the Miller Prizes, awards have been made to Messrs. A. M. Stewart and R. C. Farrell, of Glasgow, and to Mr. H. Fowler, of Manchester.

A fourth series of Special Visits to Works near London was successfully carried out on the 9th and 10th of May, the non-resident students being, as on previous occasions, well represented. On the first day the School of Military Engineering and the Royal Dockyard at Chatham were visited, the party numbering 65; and on the following day an equal number inspected the Municipal Works of Ealing, the Great Wheel in course of erection at Earl's Court, and the Electrical Standardising Laboratory of the Board of Trade. The Students' Twentieth Annual Dinner was also held on the 10th of May, and was well attended.

The "James Forrest" Lectures.

The Council records, with its thanks to Professor W. C. Unwin, F.R.S., M. Inst. C.E., the delivery before a full and appreciative meeting, of the third lecture of the series, tracing "The History of the Experimental Study of Heat-Engines," on the 2nd of May. It will be printed in the fourth volume of the Proceedings 1894–95.

The Library Catalogue.

The Council is glad to announce the publication of the new Library Catalogue, although full advantage cannot be taken of it until the entire library is assembled and arranged in the new building. Copies of the three volumes comprising this work are in course of issue to the public libraries, and those of the educational and scientific bodies in all parts of the world, who receive the Minutes of Proceedings; and it is considered that the

catalogue has been thus rendered sufficiently accessible to all who may have occasion directly or indirectly to use the Institution library.

It may be observed that in removing the books from the library in the old premises, and placing them in the rooms in which they are temporarily stored, care has been taken to retain the original classification and press-marks, with a view to the reproduction of the arrangement as far as practicable in the new library, and the avoidance of even temporary disorganisation.

The Index to the Proceedings.

The Subject-Index to Vols. lix–cxviii, inclusive, of the Minutes of Proceedings is now in print, and copies of it will be issued during the recess.

The Collection of Paintings.

The Council has had the satisfaction of purchasing a portrait group, by Lucas, of George Stephenson and his son Robert Stephenson, Past-President.

Election of Council.

Among questions which have engaged the attention of the Council during the past year is that of affording to non-resident members opportunities of more active participation in the affairs of the Institution, by giving all those who are entitled to vote for the election of the President, Vice-Presidents, and other members of the Council, every facility for exercising that privilege consistent with the provisions of the Charters. It has, as is well known, always been the practice for votes to be given personally at the Annual General Meetings; but the Council, having regard to the large number of members whose residence or engagements at a distance from London prevent them from attending those meetings, decided to inquire whether votes could, under the Charters, be legally given otherwise than personally. The opinion of Sir Richard Webster, Q.C., and of Mr. F. R. Y. Radcliffe, has been obtained upon this question, with the result that the Council is advised that personal voting at the Annual General Meetings is, under the terms of the Charters existing, absolutely necessary; and Counsel add to this opinion the statement, "If it is the desire of the Institution that Members not present at the Meeting should be able to take part in the election of the Officers

by means of voting papers, we think that application should be made for a Supplemental Charter, which there would be no difficulty in obtaining, if the desire of the Corporate Members were expressed by a substantial majority."

The Premises.

In anticipation of the early commencement of the work in connection with the rebuilding of the premises, temporary offices were taken at No. 9, Great George Street, into which a large portion of the library and other effects was moved in July—the remaining property of the Institution being warehoused.

Tenders were invited in August for the construction of the new building in accordance with the designs of Mr. Charles Barry, referred to in the last Annual Report; and the tender of Messrs. Mowlem & Co. having been accepted, the work was commenced in the autumn, a principal stipulation being that the premises should be ready for occupation on the 30th of October, 1895, in readiness for the Session 1895–96, the old meeting-room and the rooms underneath it being left intact for the business of the Session now ended.

The exceptionally severe weather of the past winter has, however, interfered considerably with the progress of the works; and on an application from the Contractors, the Council recommended to the Ordinary Meeting on the 2nd of April that the meetings of the current Session should be discontinued after the 9th of that month, with the exception of such meetings as might be required for particular purposes specified in the By-laws, and that possession of the entire premises should be given to the Contractors as early as possible, in order to facilitate their work.

This recommendation having been adopted, the whole of the old premises were entirely vacated and placed in the Contractors' hands on the 17th of April; and by the courtesy of the Council of the Royal United Service Institution, arrangements were made for the "James Forrest" Lecture to be delivered, and for the Annual General Meeting to be held, in the Theatre of that Society.

It is premature at the present moment to make any definite statement as to the occupation of the new premises, but the Council has taken all the steps in its power to ensure that the building operations may be so carried out as to interfere as little as possible with the business of the Institution and the accommodation of the members.

[Abstract of Receipts and Expenditure.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.

	£.	s.	d.	£.	s.	d.	£.	s.	d.
To Balance, April 2nd, 1894, viz.:—									
On Deposit				10,000	0	0			
Cash in the hands of the Treasurer . . .				634	10	11			
" " " Secretary . . .				43	1	2			
							10,677	12	1
INCOME.									
— Subscriptions:—									
Arrears	673	11	6						
Current	15,651	17	6						
Advance	614	15	6						
				16,940	4	6			
— Library Fund				143	18	0			
— Minutes of Proceedings:—Re-payment for Binding, &c.				425	12	10			
— Dividends: 1 year on									
£ — *Institution Dividends.*									
6,000 2¾% Consols . . .	159	13	5						
6,000 Metropolitan Board of Works 3½% Stock .	203	4	5						
6,000 Great Eastern Railway 4% Debenture Stock.	232	5	0						
8,000 Great Northern Ry. 3% Debenture Stock . .	232	5	0						
6,000 Great Western Ry. 4% Debenture Stock . .	232	5	0						
8,000 Lancs. & Yorks. 3% Do.	232	5	0						
6,000 London & N.W. 3% Ditto (6 mos. dividend on £10,667 and 6 mos. dividend on £6,000)	242	0	1						
10,000 London & S.W. 3% Ditto	290	6	3						
8,000 Midland Ry. 3% Ditto .	232	5	0						
6,000 North Eastern 4% Ditto	232	5	0						
£70,000 Nominal or par value.				2,288	14	2			
Whitworth Legacy.									
£1,400 5% Debenture Stock in Sir Joseph Whitworth & Co., Ltd. . . .	67	16	3						
4,000 Four hundred £10 shares in Ditto	80	0	0						
£5,400 Nominal or par value.				147	16	3			
— Rents—No. 26 Great George St.	150	0	0						
No. 27 Great George St.	813	19	0						
— Interest on Deposit	51	0	7						
				1,014	19	7			
— Payment for dilapidation of offices in No. 27 Gt. George St.				8	18	6			
							20,970	3	10
Carried forward							£31,647	15	11

from the 2ND APRIL, 1894, *to the* 30TH MARCH, 1895.

EXPENDITURE.

Cr. GENERAL EXPENDITURE.

	£.	s.	d.	£.	s.	d.	£.	s.	d.
By House and Establishment Charges:—									
Repairs:— Nos. 24 & 25 Great George Street	147	19	5						
No. 27 Gt. George St.	10	12	6						
				158	11	11			
Rent of No. 27 Great George Street (inclusive of agents' charges for letting offices)				588	1	0			
Rates and Taxes:—									
Reduced: Nos. 24 & 25 Great George Street	423	7	5						
Reduced: No. 26 Gt. George St.	56	2	3						
No. 27 Gt. George St.	204	15	9						
				684	5	5			
Insurance:—Nos. 24 & 25 Great George Street	7	3	3						
No. 26 Gt. George St.	2	5	0						
No. 27 Gt. George St.	6	2	0						
Furniture, &c.	20	0	0						
				35	10	3			
Rent of Telephone				22	2	0			
Fixtures and Furniture				77	15	4			
Painting of George and Robert Stephenson by Lucas				150	0	0			
Lighting and Warming:—									
Nos. 24 & 25 Great George Street	144	8	2						
No. 26 Gt. George St.	25	2	6						
No. 27 Gt. George St.	13	8	1						
				182	18	9			
Refreshments at Meetings				64	12	4			
Assistance at Meetings				17	0	0			
Monthly Receptions				62	16	8			
Students' Meetings and Visits				145	5	4			
Household Expenses				207	12	9			
							2,396	11	9
— Postages, Telegrams, and Parcels				270	11	10			
— Stationery and Printing				666	5	4			
— Watt Medals				4	15	0			
— George Stephenson Medal				2	7	6			
— Diplomas				40	15	5			
— Annual Dinner (balance of 1894 and part 1895)				270	18	4			
							1,255	18	5
— Salaries				3,095	16	8			
— Clerks, Messengers, and Housekeeper				1,101	1	10			
— Retiring Allowance to late Librarian				200	0	0			
— Donations to late Housekeeper and Messenger				82	0	0			
							4,478	18	6
— Library:—Books and Periodicals				324	18	1			
Binding				152	14	11			
Revision and printing of Catalogue (on account)				1,326	15	8			
							1,804	8	8
Carried forward							£9,935	12	4

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

Dr.

RECEIPTS—*continued.*

			£.	s.	d.
Brought forward			31,647	15	11

CAPITAL.

	£.	s.	d.	£.	s.	d.
To Admission-Fees	3,364	4	0			
— Life-Compositions	281	8	0			
— Sale of old Building Material	75	0	0			
— Sale of £4,667 London and North-Western Railway 3 % Debenture Stock . . .	5,212	9	2			
				8,933	1	2
Carried forward . .				£40,580	17	1

from the 2ND APRIL, 1894, *to the* 30TH MARCH, 1895.

EXPENDITURE—*continued*.

Cr.				£. s. d.
Brought forward				9,935 12 4
By Publications:—			£. s. d.	
"Minutes of Proceedings," Vols. cxvi., cxvii., cxviii. and cxix.			7,970 19 11	
Subject Index, vols. lix.–cxviii. (on account) .			100 0 0	
Charters, By-Laws, and Lists of Members . .			130 16 8	
				8,201 16 7
— Legal Expenses:—				
Westminster (Parliament Street) Improvements Bill			67 2 9	
General			7 17 0	
				74 19 9
— Succession Duty on Palmer Bequest				173 2 3
				£18,385 10 11
CAPITAL.				
By New Building—				
Contract			4,810 0 0	
Architect:—Commission . . .	210 10 0			
Miscellaneous preliminary services . .	231 5 0			
			471 15 0	
Clerk of the Works			126 0 0	
Model of New Building.			22 1 10	
Repairs to temporary premises			193 13 4	
Rent of ditto (9 months *less* allowance for repairs)			512 10 0	
Rates and Taxes on ditto (9 months)			141 10 7	
Insurance of ditto			2 5 0	
Lighting and Warming of ditto			38 10 0	
Removing, fitting up Library, Warehousing, &c.			527 10 2	
Legal Expenses			284 13 0	
				7,130 8 11

Carried forward . . £25,515 19 10

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*continued.*

Dr.				£. s. d.
	Brought forward			40,580 17 1
	Trust-Funds.			
	Telford Fund.	£. s. d.	£. s. d.	
To Dividends:—1 year on				
£. s. d.				
5,439 11 0	2¾% Consols	144 15 6		
3,299 2 0	Ditto (Unexpended Dividends) . . .	87 15 11		
£8,738 13 0			232 11 5	
	Manby Donation.			
£250 0 0	Great Eastern Ry. 4% Debenture Stock		9 13 6	
	Miller Fund.			
3,125 0 0	2¾% Consols.	83 3 2		
2,004 17 5	Ditto (Unexpended Dividends). . . .	53 7 1		
£5,129 17 5			136 10 3	
	Howard Bequest.			
£551 14 6	2¾% Consols		14 13 7	
	Trevithick Memorial.			
£103 0 0	2¾% Consols		2 14 9	
	Crampton Bequest.			
£512 15 11	2¾% Consols.		13 12 11	
	James Forrest Lectureship.			
£320 0 0	South-Eastern Ry. 5% Debenture Stock		15 9 8	
	Palmer Scholarship.			
£1,381 1 6	Metropolitan Board of Works 3% Stock (6 months' div.)		20 7 1	445 13 2
				£41,026 10 3

Summary of Investments.	£. s. d.	£. s. d.
Institution Investments		70,000 0 0
Freeholds of Nos. 24, 25 & 26 Gt. George St. .		40,000 0 0
Whitworth Legacy:—400 Shares of £10, and £1,400 5% Debenture Stock in the firm of Sir Joseph Whitworth and Co., Ltd.		5,400 0 0
Trust-Funds Investments:—		
Telford Fund	8,738 13 0	
Manby Donation	250 0 0	
Miller Fund	5,129 17 5	
Howard Bequest	551 14 6	
Trevithick Memorial	103 0 0	
Crampton Bequest	512 15 11	
James Forrest Lectureship . .	320 0 0	
Palmer Scholarship	1,381 1 6	
		16,987 2 4
		£132,387 2 4

from the 2ND APRIL, 1894, *to the* 30TH MARCH, 1895.

EXPENDITURE—*continued.*

Cr.	£. s. d.	£. s. d.	£ s. d.
Brought forward			25,515 19 10
TRUST-FUNDS.			
By Telford Premiums	313 18 10		
— Telford Medals	21 0 0		
		334 18 10	
— Miller Scholarships	80 0 0		
— Miller Prizes	61 19 8		
		141 19 8	
— James Forrest Lectureship (Second Lecture) .		15 11 0	
			492 9 6
			26,008 9 4
By Balance, March 30th, 1895, viz.:—			
On deposit		14,000 0 0	
Cash in the hands of the Treasurer		988 10 6	
" " Secretary		29 10 5	
			15,018 0 11
			£41,026 10 3

Examined with the Books and found correct.

(Signed) FRANCIS FOX, W. T. DOUGLASS } *Auditors.*

JAMES FORREST, *Secretary.*
6 *May*, 1895.

PREMIUMS AWARDED.

Session 1894–95.

The following is a detailed list of the Awards made for Original Communications submitted during the past session:—

For Papers Read and Discussed at the Ordinary Meetings.

1. A George Stephenson Medal and a Telford Premium to Albert John Durston, Engineer-in-Chief R.N., for his Paper on "The Machinery of War-ships."
2. George Stephenson Medals and Telford Premiums to John Isaac Thornycroft,[1] F.R.S., and Sydney Walker Barnaby,[1] MM. Inst. C.E., for their joint Paper "Torpedo-Boat Destroyers."
3. A Telford Medal and a Telford Premium to William Duff Bruce, M. Inst. C.E., for his Paper on "The Kidderpur Docks, Calcutta."
4. A Telford Medal and a Telford Premium to Sigvard Johnson Berg, Assoc. M. Inst. C.E., for his account of "The St. Gothard Mountain Railway and the Stanzerhorn Cable-Railway."
5. The Manby Premium to Charles Butters, and Edgar Smart, Assoc. M. Inst. C.E., for their joint Paper on "Plant for the Extraction of Gold by the Cyanide Process."
6. A Crampton Prize to John Richardson (of Lincoln), M. Inst. C.E., for "The Mechanical and Electrical Regulation of Steam-Engines."

For Papers Printed in the Proceedings without being Discussed.

1. A Telford Medal and a Telford Premium to Archibald Sharp, Wh.Sc., B.Sc., Assoc. M. Inst. C.E., for his Paper entitled "Circular Wheel-Teeth."
2. A Telford Medal to the representatives of the late Henry Gill,[2] M. Inst. C.E., for his Paper on "The Filtration of the Müggel Lake Water-Supply, Berlin."

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[1] Have previously received Watt Medals and Telford Premiums.
[2] Has previously received a Telford Premium.

3. A Watt Medal and a Crampton Prize to John Alfred Griffiths, B.Sc., Wh.Sc., Assoc. M. Inst. C.E., for his Paper on "Windmills for Raising Water."
4. A Watt Medal and a Crampton Prize to Alfred John Hill, Wh.Sc., Assoc. M. Inst. C.E., for his Paper, "Repairs and Renewals of Railway Rolling-Stock."
5. A Telford Premium to Oscar Guttmann, Assoc. M. Inst. C.E., for his account of "The Removal of the 'Iron Gates' of the River Danube."
6. A Telford Premium to Charles August Leibbrand (of Stuttgart), for his Paper "On a Concrete Bridge at Munderkingen."
7. A Telford Premium to Adam Scott, Assoc. M. Inst. C.E., for his Paper entitled "Deep Water Quays at Newcastle-upon-Tyne."
8. A Telford Premium to David Cunningham, F.R.S.E., M. Inst. C.E., for his Paper on "The Estuary of the Tay."

For Papers Read at the Supplemental Meetings of Students.

1. A Miller Prize to William Garnys Wales,[1] Stud. Inst. C.E., for his Paper entitled "Caissons and Gates for closing Lock and Dock Entrances."[2]
2. A Miller Prize to Samuel Henry Barraclough, B.E., Stud. Inst. C.E., for the Paper, contributed jointly with Lionel S. Marks, B.Sc., entitled "Some Experiments on the Heat-losses to the Cylinder-Walls of a Steam-Engine."[2]
3. A Miller Prize to Edward Ewing Matheson, Stud. Inst. C.E., for his description of "Timbering in the Ampthill Second Tunnel."[2]

For Papers Read before Local Associations of Students.

1. A Miller Prize to Angus Matheson Stewart, Stud. Inst. C.E. (of Glasgow), for his account of "The Glasgow District Subway."[2]
2. A Miller Prize to Richard Craig Farrell, Stud. Inst. C.E. (of Glasgow), for his description of "The Permanent Way and Signalling of the Glasgow Central Railway."
3. A Miller Prize to Henry Fowler, Stud. Inst. C.E. (of Manchester), for his Paper on "The Testing and Inspection of Plates."

[1] Has previously received a Miller Prize.

[2] It has been determined to print an Abstract of this Paper in the Minutes of Proceedings.

SUBJECTS FOR PAPERS.

Session 1895–96.

The Council of the Institution of Civil Engineers invites Original Communications on the Subjects included in the following List, as well as on any other questions of professional interest. This list is to be taken merely as suggestive, and not in any sense as exhaustive. For approved Papers the Council has the power to award Premiums, arising out of Special Funds bequeathed for the purpose, the particulars of which are as under:—

1. The Telford Fund, left "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) produces £235 annually.

2. The Manby Donation, of the value of about £10 a year, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings."

3. The Miller Fund, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) realises nearly £140 per annum. Out of this Fund the Council has established a Scholarship,—called "The Miller Scholarship of The Institution of Civil Engineers,"—and is prepared to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years. No Paper will be received from a Student in competition for the Miller Scholarship and the Miller Prizes when he has become qualified by age, viz. twenty-five years, for election into the Corporation.

4. The Howard Bequest, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the Uses or Properties of Iron or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." The annual income amounts to nearly £15. It has been arranged to award this prize every five years,

commencing from 1877. The next award will therefore be made in 1897.

5. The CRAMPTON BEQUEST of £500, free of legacy duty, has been invested in the purchase of £512 15*s.* 11*d.* 2¾ per cent. consols, and the income arising therefrom is now £13 14*s.* This trust is for the purpose of founding "a Prize to be called the 'Crampton Prize,' so that the interest of the said legacy shall be annually expended in a medal or books or otherwise . . . . for presentation to the Author of the best Paper on 'The Construction, Ventilation and Working of Tunnels of Considerable Length,' or failing that then on any other subject that may be selected."

6. The balance of the TREVITHICK MEMORIAL FUND, amounting to £100 0*s.* 9*d.*, has been accepted for a periodical Premium to be called after Richard Trevithick. This sum has been placed in £103 2¾ per cent. consols, upon which the interest is £2 15*s.* a year.

The Council will not make any award unless a communication of adequate merit is received, but will give more than one Premium if there are several deserving memoirs on the same subject. In the adjudication of the premiums no distinction will be made between essays received from members of the Institution or strangers, whether Natives or Foreigners, except in the cases of the Miller and the Howard bequests, which are limited by the donors.

LIST.

1. The most economical Methods of Handling large masses of Excavation, as exemplified in modern canal construction.
2. The Measures necessary for the improvement of Canal Navigations.
3. The Methods adopted in carrying out large Dock and Harbour Works, with descriptions of the Plant employed.
4. The Appliances for Dredging and for Removing Rock in deep water, with details of the time occupied in the various operations.
5. The Application of Compressed Air, steam and hydraulic power to Rock-drills.
6. The Construction, Equipment, and Working of Light or Economical Railways of a permanent character.
7. The Design and Construction of Railway Carriages, having reference to (*a*) lavatory accommodation; (*b*) provision for refreshments; and (*c*) sleeping arrangements.

8. The Use of Compressed Air in Subaqueous Tunnelling.
9. The Modern Methods of Pumping compared as to cost and efficiency.
10. The Use of Steel in the Construction of large Water-Tanks.
11. The Employment of Storage-Reservoirs in Irrigation and in the Conservation of Rivers.
12. The Purification of Sewage by precipitation, filtration, electrolytic, bacteriological and chemical processes.
13. The Use of Ash-bin Refuse in towns for the production of steam.
14. The Purification of large quantities of Water after its use in Manufactories.
15. The Methods of Enriching Coal-Gas and their effect on its calorific and illuminating values.
16. The Production and Enrichment of Water Gas.
17. The methods of conveying and of using Natural Gas.
18. The Utilization of Heat (*a*) generated in the compression of air and other gases; (*b*) carried away by steam-engine condenser-water; and (*c*) contained in boiler-furnace flue-gases.
19. The Methods of Condensing Steam by the use of moderate quantities of water.
20. The Methods of removing Moisture from Steam, and of reducing losses by radiation from steam-pipes.
21. The Production and Use of Super-heated Steam.
22. The Theory and Development of the Compound Steam-Turbine.
23. The Recent Developments in Gas-Engines and Oil-Engines, including a comparison of the relative merits of the several Cycles, with reference to "after-burning."
24. The Application of Oil- and Gas-Engines to tractive purposes on common roads and on tramways, and to the propulsion of vessels.
25. The Design and Construction of large Turbines.
26. The Methods of Testing the Lubricating Values of Oils, Greases, etc.
27. The Comparative Merits of Blast- and Reverberatory Furnaces.
28. The Influence of Carbon on Iron.
29. The Magnetic Properties of Iron and Steel.
30. The Manufacture of Steel for Structural Purposes.
31. The Strength of Steel Shafts, Tubes and Cylinders.
32. The Mining of Thin Seams of Coal.
33. The Underground Arrangements in Collieries.

34. The Influence of Coal-dust in producing Colliery Explosions.
35. The Efficiency of Centrifugal Fans for forced draught and for the Ventilation of Mines.
36. The Drainage of Mines by Pumping and by Tunnelling.
37. The Extraction of Metals from their Ores by electrolytic processes.
38. Argentiferous Lead Smelting in Water-jacketed blast-furnaces.
39. The Methods of Gold-mining in California.
40. The Occurrence, Production and Uses of (*a*) Asbestos, (*b*) Arsenic, and (*c*) Mercury.
41. Aluminium, its manufacture, properties, uses and alloys.
42. The Metallurgy of Chromium, Molybdenum and other rare metals, and their use in the Manufacture of Steel.
43. The design, construction, erection and working of Modern Stamp Mills.
44. The Machines for Raising Mineral Tailings, as lifting-wheels, pumps, dredgers, etc.
45. The most suitable Steam-power Equipments for Electric-light stations.
46. The Utilization of Electric-Lighting Plant during hours of small demand.
47. The Utilization of Electrical Energy in the form of heat.
48. The Regulation of Electric pressure in large lighting circuits as carried out at the engine, the dynamo, or the exciter.
49. The Theory and Practice of the Transmission of Power by Alternating Currents.
50. The Use of Electrical Motors for driving machines in textile factories and in engineering workshops.
51. The first cost, facility and economy of operation of Electrical Traction on Railways with heavy trains and on Tramways.
52. The Construction and Working of Electrical Lifts and Cranes.
53. The Electrolytic Action of Return Currents in Electrical Tramways on gas- and water-mains, and the best means of providing against Electrical Disturbances.
54. The most suitable Alloys for the working parts of Pumps for lifting corrosive liquids from mines, &c.
55. The Methods of Preventing or Arresting the Corrosion of Hydraulic Rams of large diameter.
56. The Use of the Die-press in workshop operations.
57. The Modern Rolling-Mills of the United States.
58. The Appliances used in the Manufacture of Smokeless Powder.
59. The Transport, Storage and Manipulation of Grain.

60. The different systems of Refrigeration, and of appliances for the storage and Preservation of Food Produce.
61. Brine-pumping and the Manufacture of Common Salt.
62. The present Limits of Speed at Sea.
63. The most recent types of (*a*) Passenger and Mail Steamers; (*b*) Cargo-Steamers.
64. The Relative Advantages of Single-Screws, of Twin-Screws, and of Triple-Screws in large vessels.
65. The Use of Electrical Machinery for lighting and the transmission of power in warships and in the mercantile marine.
66. The best position for Torpedo-Discharging Tubes on large vessels, with a fixed direction, or trainable.

Instructions for Preparing Original Communications.

In writing these Essays the use of the first person should be avoided. They should be legibly transcribed on foolscap paper, on one side only, leaving a margin on the left side, in order that the sheets may be bound. Every Paper must be prefaced by an Abstract of its contents not exceeding 1,500 words in length.

Illustrations, when necessary, should be drawn on tracing-paper, to as small a scale as is consistent with distinctness, but in no case should any Fig. exceed 6½ inches in height. When an illustrated communication is accepted for reading, a series of Diagrams will be required so drawn and coloured as to be clearly visible at a distance of 60 feet. These diagrams will be returned.

Papers which have been read at the Meetings of other Societies, or have been published, will not be accepted. According to the By-laws every Paper presented to the Institution is deemed to be its property, and may not be published without the consent of the Council.

The Communications must be forwarded to the Secretary, from whom any further information may be obtained. There is no specified date for the delivery of MSS., as when a Paper is not in time for one session it may be dealt with in the succeeding one.

William Pole, *Honorary Secretary*,
James Forrest, *Secretary*.

The Institution of Civil Engineers,
Great George Street, Westminster, S.W.
August, 1895.

Excerpt By-Laws, Section XV, Clause 3.

"Every Paper, Map, Plan, Drawing, or Model, presented to the Institution shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. Except as hereinbefore provided, no person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

Notice.

It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors have advanced somewhat doubtful theories, or have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat that the Institution as a body must not be considered responsible either for the statements made, or for the opinions expressed in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the inquiry; but that such notice, or award, must not be regarded as an expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

ORIGINAL COMMUNICATIONS.

RECEIVED BETWEEN APRIL 1, 1894, AND MARCH 31, 1895.

AUTHORS.

Abell, W. P. No. 2,845.—Bagasse and Refuse Furnaces. With an Abstract, Specimens, and numerous illustrations.

Aitken, T. No. 2,894.—The Maintenance of Macadamised Roads. With 1 Tracing. (*Post*, p. 215.)

Allen, P. R. No. 2,832.—The Periyar Project Tunnel. With 5 Tables and 7 Drawings.

Amoretti, P. No. 2,848.—Steam Tramways in Italy. With an Appendix, 1 Plate and 18 Figs. (Vol. cxix. p. 344.)

Bagnall, G. No. 2,846. Long-distance Levelling. With 3 Tables and 2 Tracings. (Vol. cxxi. p. 152.)

Barr, G. M. No. 2,886.—Otago Upper Harbour Improvement Works, New Zealand. With 1 Drawing. (Vol. cxxi. p. 200.)

Booth, R. B. No. 2,819.—The Rajkot Waterworks, Bombay. With an Appendix and 3 Drawings. (Vol. cxix. p. 264.)

Bowes, A. No. 2,806.—The Treatment of Sewage by Polarite. With an Abstract. (Vol. cxvii. p. 305.)

Brady, A. B. No. 2,835.—Restoration of the Fitzroy Suspension-Bridge, Rockhampton, Queensland. With 2 Lithographs, 6 Photographs and Specifications. (Vol. cxxi. p. 195.)

———. No. 2,852.—The partial destruction by Flood, and temporary restoration, of the Victoria Bridge over the Brisbane River. With 3 Drawings, Photograph and Specification.

———. No. 2,880.—Some Examples of Low-level Bridges in Queensland. With Appendix and 4 Drawings.

Brebner, A. No. 2,896.—Powers of Lighthouse-Lights. With 2 Drawings. (*Post*, p. 300.)

Britton, P. W. No. 2,815.—The Transport, Storage, and Manipulation of Grain. With an Abstract.

Butters, C., and Smart, E. No. 2,866.—Plant for the Extraction of Gold by the Cyanide Process. With an Abstract, 10 Drawings and 5 Photographs. (Vol. cxxi. p. 1.)

AUTHORS.

Cash, J. No. 2,816.—The Construction of a Concrete Wharf at Portslade, Sussex. With 2 Drawings. (Vol. cxviii. p. 392.)

Clerk, D. No. 2,897.—Recent developments in Gas-Engines. With 4 Appendixes and 8 Drawings.

Clerke, W. J. B. No. 2,860.—Note on the Flood-Discharge of the Tansa Catchment-Area. (Vol. cxix. p. 280.)

Cooper, C. H. No. 2,871.—Footways. With 2 Tables and 1 Drawing. (*Post*, p. 208.)

Cowan, D. No. 2,865.—Ironfounding. Light Castings; their production and combination as practised in the Falkirk District. With 3 Drawings.

Crimp, W. S., and Bruges, E. No. 2,849.—A New Formula for the Flow in Sewers and Water-Mains. With Tables and 9 Drawings. (*Post*, p. 198.)

Cunningham, D. No. 2,823.—The Estuary of the Tay. With 15 Tracings. (Vol. cxx. p. 299.)

————————. No. 2,824.—Description of a Caisson and Swing-Bridge at Dundee Harbour. With 2 Drawings.

Davey, H. No. 2,854.—Steam-Engine Economy: Condensing Engines. With 3 Tables and 11 Drawings. (*Ante*, p. 1.)

Donkin, B. No. 2,869.—Experiments on Centrifugal Blowing-Fans. With Notes on the Measurement of Air in Pipes. With an Abstract and 10 Drawings. (*Post*, p. 265.)

Durston, A. J. No. 2,831.—The Machinery of War-Ships. With 5 Tables and 6 Drawings. (Vol. cxix. p. 17.)

Fairley, W. No. 2,841.—The Main Drainage and Sewage Disposal of Edinburgh. With 1 Drawing. (Vol. cxxi. p. 226.)

Greathead, J. H. No. 2,873.—The City and South London Railway; with some remarks upon Subaqueous Tunnelling by Shield and Compressed-air. With 30 Figs.

Harington, H. S. No. 2,836.—Note on the Cost of Lofty Railway-Bridges. With 14 Tracings.

Hay, R. No. 2,814.—Water-power applied by Electricity to Gold-Dredging. (Vol. cxxi. p. 55.)

Heenan, H., and Gilbert, W. No. 2,857.—The Design and Testing of Centrifugal Mine-ventilating Blast-Fans. With an Abstract and 10 Plates.

Hill, A. E. B. No. 2,833.—The New Westminster Waterworks. With an Abstract, 10 Drawings and 5 Specifications. (*Post*, p. 193.)

AUTHORS.

Hill, A. J. No. 2,820.—Repairs and Renewals of Railway Rolling-Stock. With 25 Tables. (*Post*, p. 224.)

Hodge, H. W. No. 2,825.—The Pecos Viaduct, Texas, U.S.A. With 2 Photographs and 9 Tracings. (Vol. cxx. p. 314.)

Holme, C. H. No. 2,843.—The new Cart-Road into Naini Tal. With 6 Photographs and 1 Drawing.

Hooley, E. P. No, 2,862.—Tarred Foot-paths in Rural Districts. With a Sketch. (*Post*, p. 205.)

Hunt, A. E. No. 2,882.—Aluminium: the American practice and Plants for its Manufacture. With an Abstract, 1 Map, 1 Tracing and 3 Photographs.

Jones, C. No. 2,809.—The Birkenhead Ferry-boats "Wirral" and "Mersey." With 1 Drawing. (Vol. cxviii. p. 267.)

Kayser, H. W. F., and Provis, R. No. 2,874.—Tin-Mining and Dressing at Mount Bischoff, Tasmania. With an Abstract and 12 Drawings.

Kennedy, R. G. No. 2,826.—The Prevention of Silting in Irrigation Canals. With 1 Tracing. (Vol. cxix. p. 281.)

Kenny, W. E. No. 2,804.—Machinery for carrying out Sea-Works. With 6 Drawings. (Vol. cxix. p. 299.)

Kraft, J. No. 2,891.—Covers and Conical Pistons without Ribs. With 5 Drawings.

Kühl, C. H. L. No. 2,855.—Cost of Dredging in the Lower Danube. (Vol. cxix. p. 222.)

Liddle, W. No. 2,876.—Railway Construction in the Philippine Islands. With 10 Drawings and 10 Photographs. (Vol. cxxi. p. 170.)

Macdougall, A. No. 2,877.—Repairs to a Submerged Water-Main, Toronto Waterworks. With a Plan.

Mears, B. D. No. 2,889.—Notes on the Evaporative value of Bengal Coal.

Moir, E. W. No. 2,834.—Tunnelling by Compressed-Air.

Naylor, W. No. 2,895.—Plant for the Treatment of Trades' Waste. With an Abstract and 10 Drawings.

Nicols, O. F. No. 2,885.—The Brooklyn Elevated Railroad. With an Abstract and 7 Drawings.

Palmer, P. H. No. 2,861.—The Salt-water Supply of Hastings. With 2 Drawings.

Parsons, Hon. R. C. No. 2,884.—A Description of the Health Improvement Works of the City of Buenos Ayres, Capital of the Argentine Republic. With 4 Appendixes and 43 Drawings.

AUTHORS.

Pinnington, G. No. 2,856.—On a means of raising Water to any height, or forcing it against any pressure, whilst having only friction of the moving parts of a machine to overcome.

Pole, W. No. 2,813.—Notes on the Manufacture of Coal-Briquettes as carried out in France in 1872. (Vol. cxviii. p. 385.)

Popplewell, W. C., and Coker, E. G. No. 2,853.—The Torsional Strength of Solid and Hollow Shafts. With an Abstract and 13 Drawings. (*Post*, p. 291.)

Pownall, C. A. W. No. 2,822.—The Usui Mountain Railway, Japan. With 3 Drawings. (Vol. cxx. p. 43.)

Richardson, J. No. 2,859.—The Mechanical and Electrical Regulation of Steam-Engines. With 1 Plate and 6 Figs. (Vol. cxx. p. 211.)

Robertson, R. No. 2,837.—Electrical Haulage at Earnock Colliery. With an Abstract and 5 Tracings. (Vol. cxxi. p. 47.)

————. No. 2,851.—Ardrossan Harbour Extensions. With an Abstract and 13 Drawings. (Vol. cxx. p. 289.)

Rowlandson, C. A. No. 2,839.—The Bold Street Extension Tunnel and Central Low-Level Station of the Mersey Railway. With 4 Drawings.

Sandeman, J. W. No. 2,892.—Portland Cement and Concrete. (Vol. cxxi. p. 214.)

Scott, A. No. 2,812.—Deep-Water Quays at Newcastle-upon-Tyne. With an Appendix, an Abstract, 3 Tracings and 2 Photographs. (Vol. cxix. p. 291.)

Smith, M. No. 2,878.—The Canadian Trans-Continental Railway. With 3 Maps and 3 Drawings.

Steavenson, A. L. No. 2,875.—Cleveland: its Mineral Field and Iron Mines. With 2 Drawings.

Szlumper, A. W. No. 2,858.—Re-construction and widening of Barnes Bridge, London and South-Western Railway. With 5 Drawings and 15 Photographs.

Thompson, J., jun. No. 2,887.—Wallsend Graving-Dock on the Tyne. With 2 Drawings and 5 Photographs. (Vol. cxxi. p. 208.)

Thompson, R. W. No. 2,811.—Setting of the Iron Caisson at the North Pier-head, Madras Harbour. With 2 Drawings.

Thornycroft, J. I., and Barnaby, S. W. No. 2,879.—Torpedo-Boat Destroyers. With 17 Tracings. (*Ante*, p. 51.)

Twinberrow, J. D. No. 2,817.—Railway Passenger Carriages. With 4 Drawings.

AUTHORS.

Vernon-Harcourt, L. F. No. 2,883.—Brief Notices of Works. Portland Harbour; the Severn Tunnel; the Forth Bridge; the River Clyde; the River Tyne; the Tower Bridge. (Vol. cxxi. p. 303.)

Wain, E. B. No. 2,838.—Colliery Surface-Works. With 12 Tracings. (Vol. cxix. p. 123.)

Young, E. W. No. 2,818.—Surveying with the Omnimeter. With 1 Tracing. (Vol. cxvii. p. 296.)

Young, H. W., and Edwards, W. C. No. 2,881.—Small Cylindrical Bridge-Piers, New Zealand Midland Railway. With 4 Drawings and 5 Photographs. (*Post*, p. 283.)

LIST OF DONORS TO THE LIBRARY.

FROM APRIL 1, 1894, TO MARCH 31, 1895.

A.

Aburrow, C.
Académie Royale de Belgique.
Accademia Pontificia dei Nuovi Lincei.
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Admiralty.
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American Railway Master Mechanics' Association.
American Society of Civil Engineers.
American Society of Irrigation Engineers.
American Society of Mechanical Engineers.
American Society of Naval Engineers.
Ammann, P.
Anderton, B., B.A.
"Annalen für Gewerbe und Bauwesen."
"Annales Industrielles."
Architekten- und Ingenieur-Verein zu Hannover.
Asiatic Society of Bengal.
Association alsacienne des Propriétaires d'Appareils à Vapeur.
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Astronomer Royal, Greenwich.
"Athenæum, The."
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"Australian Irrigation Colonies, The."

B.

Bahia and San Francisco Railway Company, Limited.
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British Association.
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"Bulletin du Canal de Suez."
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Bureau of Ethnology, Washington, U.S.A.
Bureau of Steam Engineering, Washington, U.S.A.
Burton, Prof. W. K.
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C.

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Cambridge Philosophical Society.

Camera Club, The.
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"Centralblatt der Bauverwaltung."
Centralbureau für Meteorologie und Hydrographie im Grossherzogthum Baden.
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Churruca, E. de.
City and Guilds of London Institute.
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Civil Engineering College, Sibpur.
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Collegio degli Ingegneri ed Architetti in Napoli.
Collegio degli Ingegneri ed Architetti in Palermo.
"Colliery Engineer, The."
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Colonial Secretary, Cape Town.
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Comité des Forges de France.
Commissão Geographica e Geologica de São Paulo.
Commission de Météorologie du Département des Bouches-du-Rhône.
Committee of Locomotive and Carriage Superintendents for India, Simla.
Congrès international de Navigation intérieure, The Hague.
Congresso degli Ingegneri e degli Architetti in Palermo nel 1892.
Conrad, J. W.
Considère, A. G.
Constable, A.
"Contract Journal, The."
Cooke, Prof. S., M.A.
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Cooper Union for the Advancement of Science and Art.
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Crosby Steam Gauge and Valve Company.
Crowell, J. F.
Cunard Steamship Company, Limited.
"Czasopismo Techniczne."

D.

Dansk Ingeniörforeningen.
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Department of Labor, Washington.
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Dépôt des Phares, Paris.
"Deutsche Bauzeitung."
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E.

East of Scotland Engineering Association.
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"Electrical Engineer, The."
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"Engineer, The."
"Engineering."
Engineering Association of New South Wales.
"Engineering News."
"Engineering Record."
Engineers' Club of Philadelphia.
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F.

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G.

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Iron and Steel Institute.
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J.

Jackson, W.
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"Journal of Gas Lighting."
Judson, W. P.
Junior Engineering Society. (*Now* Institution of Junior Engineers.)
Just, C. F.

K.

Karachi Port Trust.
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London County Council.
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M.

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Massachusetts Institute of Technology.
Master Car-Builders' Association, Chicago.
Matthewman, F. A.
Matthews, William (Southampton).
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Meteorological Department, Calcutta.
Meteorological Office, Bombay.
Meteorological Office, London.
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Meyer, F. A.
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Midland Institute of Mining, Civil and Mechanical Engineers.
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Ministerio de Industria y Obras Públicas, Santiago de Chile.
Ministero dei Lavori Pubblici, Rome.
Moncrieff, A. B.
"Moniteur Industriel, Le."
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Moore, Robert.
Mordey, W. M.
More, C. J.
Moreau, G.
Morison, G. S.
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N.

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Navy Department, U.S.A.
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New Zealand University.
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North British Railway Company.
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Odling, C. W., M.E.
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Ordnance Office, Washington, U.S.A.
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Owens College, Manchester.

P.

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Perrot, S. de.
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Physical Society of London.
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Q.

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R.

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Railway Commissioners of New South Wales.

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"Revista de Obras Publicas," Lisbon.
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S.

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"Schweizerische Bauzeitung."

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South African Association of Engineers and Architects.
South African Philosophical Society.
South Australian Railway Commissioners.
South Australian School of Mines and Industries and Technological Museum.
South London Tramways Company.
South Wales Institute of Engineers.
Sperry, E. A.
Spolku Architektů a Inženýrů v království Ceském.
Spon, E. and F. N.
State Board of Health of Massachusetts.
State Board of Health of New York.
Stevens Institute of Technology.
Stevenson, C. A., B.Sc., F.R.S.E.
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"Street Railway Journal."
Stuart, D. M. D.
Sugg, W.
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Survey of India Department.
"Surveyor, The."
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T.

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"Transport."
Trautwine, J. C., Jun.
"Travelers' Official Guide of the Railway and Steam Navigation Lines in the United States and Canada."
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Trevithick, R. F.
Trinity University, Toronto.

U.

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W.

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Goodman, James	1	1	0
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Grinling, A. J.	3	3	0
Heathcote, C. F.	3	3	0
Hobley, C. W.	1	1	0
Holford, W. G.	10	10	0
Houghton, S. A.	1	1	0
Humphreys, A. C.	3	3	0
Carried forward	£78	1	6

	£.	s.	d.
Brought forward	78	1	6
Hutchison, G. L.	2	2	0
Joyce, Alfred	2	2	0
Kolle, H. W.	3	3	0
Kyle, John, Jun.	2	2	0
Laing, Andrew	5	5	0
Martin, E. M.	1	1	0
Mauldin, P. J.	2	2	0
Mawson, M.	1	1	0
Morris, G. E.	1	1	0
Newton, C. B.	1	1	0
Olive, L. W.	1	1	0
Oliver, A. M.	5	7	6
Pooley, H.	1	1	0
Preller, C. S. Du Riche	1	0	0
Rathbone, A. L.	2	12	6
Rutter, C. H.	2	2	0
Schloesser, R.	0	4	6
Scriven, C. W.	1	1	0
Scrutton, L.	1	1	0
Smeaton, S.	1	1	0
Smith, W. C. C.	1	1	0
Stephens, G. H.	5	0	0
Stewart, J. Vaughan	1	1	0
Stourton, A. P. J.	5	0	0
Stride, H. W.	1	1	0
Suggate, A.	2	2	0
Swinnerton, R. A. W.	1	0	0
Thomasson, L.	2	2	0
Venn, E. G.	1	1	0
Watson, F. M.	1	10	0
White, S. H.	1	1	0
Wilson, C. L. N.	1	1	0
Worth, J. E.	3	3	0
Zeal, W. A.	2	2	0
Total	£143	18	0

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JAMES FORREST.

EXTRA MEETING.

2 May, 1895.

SIR ROBERT RAWLINSON, K.C.B., President, in the Chair.

THE "JAMES FORREST" LECTURE.

The PRESIDENT said it was his duty and pleasure to introduce Professor Unwin, who had kindly consented to give the third "James Forrest" lecture. It would be learnt with regret that Mr. Forrest was not allowed by his medical adviser to be present, and all would sympathize with him, and cordially wish that he might soon recover the strength needed to fit him for the duties of his office.

"The Development of the Experimental Study of Heat-Engines."

By Prof. WILLIAM CAWTHORNE UNWIN, B.Sc., F.R.S., M. Inst. C.E.

THE request to deliver one of this series of Lectures carried with it something of the authority of a command. I trust that that will be held to excuse, in some measure, the undertaking of what I feel is a rather serious and difficult duty. I understand it was Mr. Forrest's intention that these Lectures should illustrate the dependence of the engineer, in his practical professional work, on the mathematical and physical sciences. They therefore naturally take the form of a review of some branch of engineering with special reference to the scientific principles which have been factors in its advancement.

I selected for this Lecture the history of the experimental investigation of the steam-engine. On the one hand, the steam-engine in its many forms has been the most remarkable of all the machines which are due to the genius of engineers, and the most powerful auxiliary in the expansion during a century of engineering work. On the other hand, the creation of a science of Thermodynamics on the basis of the principle of the conserva-

tion of energy during the years 1845–55 is one of the most important advances ever made in scientific knowledge. Between 1855 and 1875, scientific men of very great intellectual eminence prosecuted researches on the action of heat motors as illustrations of thermodynamic principles, and engineers simultaneously invented many improvements and enormously extended the use of steam-power. I shall endeavour to show that the scientific advance and practical improvement of the steam-engine were not unconnected.

In a Paper recently read in this Society, an engineer, for whose practical ability and remarkable mechanical ingenuity I have the greatest respect, made the following statement: "A period of sixty-seven years has been required for the development of the principles enumerated by Watt, Trevithick and Grose; and upwards of forty years have been required for the reduction of the consumption of steam from 19 lbs. to 13 lbs. per I.HP. per hour. . . . In these advances no new principle has been applied, and no higher efficiency has been obtained. The progress has resulted from the labours of designers and makers of steam-engines—purely scientific investigation having only explained what the steam-engine should do if worked in a manner wholly imaginary." That represents, I believe, a not uncommon opinion, perhaps also a not uncommon jealousy of the intrusion of science in the field of practical engineering. It is curious that the Paper in which this occurs is not a practical Paper at all, but a theoretical Paper, in which the Author uses the data of Regnault and not altogether correctly applies the methods of Rankine. It may be noted that out of thirty-six engine-tests on which the Author bases his conclusions, half are engine-tests made by Professors. It is something that the improvement of the steam-engine is attributed to the development of principles laid down by Watt. But when Watt invented the steam-engine he was not an engineer; he was a philosophical instrument maker, and he found his principles in the laboratories of Glasgow University. Black's discovery of latent heat gave him the key to the apparently extravagant expenditure of injection water in the model Newcomen engine, and Dr. Cullen's discovery of the low temperature at which water boils in vacuo, he himself states this, led him to perceive that steam would condense in a separate vessel, and to formulate the principle that steam will take the pressure corresponding to the lowest temperature of any part of the space in which it is confined. The writer I have quoted says that "the proposal of Watt to use steam expansively, or to employ steam jackets, was not the result of abstruse investi-

gation on his part, but was due to the exercise of his common sense or genius." But when Watt patented expansive working in 1782, he had been experimenting incessantly for fifteen years on the properties of steam. "If," says this writer, "observation is confined to the actual steam-engine cycle, it is seen that in reality a properly constructed steam-engine is a highly efficient prime-mover." But surely some explanation is wanted, why we must confine our attention to a cycle which involves the rejection of nine-tenths of the heat supplied into the condenser.

It will be the object of this Lecture to show that other scientific ideas of a later date than those of Watt have been operative in promoting the improvement of the steam-engine. It is impossible to go back to the mental attitude of forty years ago, and those who assert that nothing new has been learned since that time forget that, in the interval, scientific discoveries have become commonplaces, and that they themselves reason and act on them as M. Jourdain talked prose without knowing it.

Twenty years ago, Lord Armstrong stated that of all the coal raised in this country about one-third was used for household purposes, one-third for generating steam, and one-third for iron-making and manufacturing processes. He remarked that in the first two divisions the waste of fuel was shameful, and that, without carrying economy to extreme limits, all the effects now realised from the use of coal could be obtained by an expenditure of half the quantity. The improvement of the steam-engine is mainly due to an incessant attempt to diminish the waste of fuel.

Tests of Steam-Engines in Cornwall.

Steam engineers have been face to face with the problem of economy for more than a century. Coal was excessively dear in Cornwall, and as the mines were deepened and more power was required the cost of working increased ruinously. By reducing fuel-cost Watt saved the mining industry from extinction, and he adopted the plan of taking, in payment for his engines, a sum reckoned equivalent to one-third of the fuel saved. By agreement with the miners, tests were made and the standard duty of a Newcomen engine was fixed at 7,037,000 foot-lbs. per bushel. Regular duty-determinations were made for all Watt's engines. Generally they gave a duty of 20,000,000. It is curious that though Watt had patented expansive working, his trials of it were not encouraging, and he did not use expansive working in

his Cornish engines. Watt's connection with Cornwall ceased in 1800; the duty-determinations were neglected and the engines deteriorated.

Then Captain Joel Lean, who had reorganised the machinery at one of the mines and effected great economies, started again the system of duty-trials. He and his sons carried on the work for many years and published reports of the results of the trials, in the interest not so much of engine-builders as of mine-owners. Of these reports Dr. Pole says, "The publication produced an extraordinary effect in improving the duty of the engines. Engineers were stimulated to emulation amongst themselves. The practice of reporting is thought to have been attended with more benefit to the county than any other single event, excepting only the invention of the steam-engine itself." I have placed on the wall a short Table giving the improvement of duty of the Cornish engines during the period covered by Lean's reports.

DUTY OF CORNISH ENGINES.[1]

—	Duty in Foot-lbs. per Bushel (94 lbs.) of Coal.	Lbs. of Coal per I.HP.-Hour (estimated).
Newcomen	7,000,000	26·6
Smeaton	10,000,000	18·6
Watt, 1800	20,000,000	9·3
Lean's Report, 1815 . .	52,300,000	3·6
" " 1827 . .	67,000,000	2·8
" " 1834 . .	98,000,000	1·9
" " 1840 . .	107,000,000	1·7

Highest duty of Mr. Leavitt's pumping-engine at Louisville 140,000,000 per 100 lbs. of Pocahontas Coal. Lbs. of coal per I.HP.-hour, 1·33.

In 1834, an 80-inch-cylinder engine was erected at Fowey Consols mine. In September its duty was reported as 97,800,000. Doubts having been expressed as to the accuracy of this report, a special trial of the engine was made in October in the presence of numerous engineers and mine-owners. The stroke varied from 9 feet 3 inches to 9 feet 5 inches, but the duty was calculated on the smaller value; steam-pressure, 36 lbs. to 45 lbs. per square

[1] In the Cornish trials the stroke assumed was the mean observed stroke (Pole, p. 153), but no allowance was made for slip of the pumps. Probably 10 per cent. should be deducted from the Cornish results for slip in comparing them with some modern trials. (See Wicksteed, Transactions Inst. C.E., vol. i. p. 120; Pole, "The Cornish Engine," p. 148.)

inch; strokes per minute, 4·29; duration of trial, 24½ hours; duty reported, 125,000,000.[1]

I shall show later that the creation of a new and more scientific system of testing by Hirn and his colleagues in Alsace in 1855 was the starting-point of a similar process of improvement. Quite lately there has been a revival of careful and independent engine-testing, and of the publication of the results; and records have been established which would have been thought impossible ten years ago.

The history of expansive working in Cornwall is curious. Watt completely understood the principle and patented it. But he failed to make use of it. Woolf and Trevithick re-introduced expansive working, and Woolf tried compound engines in 1812. But the compound engines were not more economical than simple engines. It is clear that the scientific conviction that expansion must be economical held its ground in spite of practical failures, and this led to repeated attempts to use steam expansively, till at last an extraordinary amount of success was achieved.

The peculiar character of the load against which the Cornish engine worked, the lifting of a heavy mass of pump-rods, contributed to force the use of expansive working. To work without shock, a large initial and gradually diminishing effort was necessary. The extraordinary economy obtained was due probably in part to the special action of the steam, the Cornish engine being virtually a compound engine, and the admission surface being protected from cooling to the condenser; partly to the great effectiveness of a steam-jacket in an engine which worked slowly and with pauses at the end of the stroke, partly to the small clearance and separate admission and exhaust valves. The lesson engineers should have learned from Cornish experience was, that in restricted conditions high ratios of expansion were economical. In this case, as in others later, engineers generalised too crudely and concluded that expansive working was always economical. A new scientific investigation was required to correct the error.

Cornish engines worked usually at four or five double strokes per minute. In such conditions the jacket had very great influence in drying the admission surface before release. When rotative engines were run at 30 revolutions to 60 revolutions per minute, the jacket was far less efficacious and the economy was reduced by the prejudicial cylinder condensation, which for many years neutralized the efforts of engineers to obtain the expected advan-

[1] See Pole, "The Cornish Engine," p. 65.

tage from expansion. It is only in the last ten years that the magnitude of the loss due to cylinder condensation has been at all generally understood.

Experiments on Boilers.

To generate steam-power economically the boiler must be efficient and the engine must be efficient, and the conditions of efficiency of boiler and engine are completely independent. Hence the early method of Watt, in which attention was paid only to fuel used and water pumped, has been replaced by a method of independent boiler- and engine-testing. The boiler uses coal and generates steam; the engine uses steam and generates power. The economy of the boiler is reckoned on the fuel; that of the engine on the steam.

The earliest systematic trials of boilers are recorded in a Paper by Mr. Josiah Parkes [1] in the second quarto volume of the Transactions of this Institution. They are interesting as showing how early engineers realised the necessity of studying experimentally the conditions of generating steam economically. Parkes obtained information about the calorific value of different coals, measured the feed and fuel, reduced his results to a rational common standard, recognised the importance of regulating properly the air-supply. If his results can be trusted, the general average evaporation in boilers at that time was $7\frac{1}{2}$ lbs. from and at 212° per lb. of coal. With improved firing, and especially with improved arrangements for air-supply, the average evaporation was $8\frac{3}{4}$ lbs. and the best $10\frac{1}{4}$ lbs. A trial in Cornwall is given in which the evaporation was $15\frac{1}{2}$ lbs. per lb. of coal, but in that case I suppose the measurements or the reduction of the results must have been defective.

As to the calorific value of coal, there has been for a long time no uncertainty of practical importance. The researches of Dulong showed that the calorific value could be ascertained from the chemical analyses very approximately. No doubt there has been a want of a convenient calorimeter for determining directly the calorific value. This want has now been supplied by the invention of the bomb calorimeter, which appears to give very trustworthy results without excessive trouble. Mr. Donkin has made it

[1] "Evaporation of Water from Steam Boilers," Transactions Inst. C.E., vol. ii. p. 161. Mr. Mair Rumley has pointed out (Minutes of Proceedings Inst. C.E., vol. lxx. p. 313) that Mr. Parkes was the first writer to call attention to the importance of independent engine- and boiler-tests.

possible to get a bomb calorimeter in a less expensive form than that first used.[1]

Different coals, at any rate the better kinds of coal, do not differ much in absolute calorific value. Used in boiler furnaces they differ more, partly from differences of mechanical aggregation, but chiefly because the more bituminous coals require a larger air-supply for tolerably smokeless combustion than those which consist chiefly of fixed carbon. The greater excess of air involves greater chimney waste. It is to test the commercial calorific value that Prof. Schröter has established in Munich a heat laboratory where fuels can be tested on a large scale and under ordinary practical conditions of combustion. The arrangements permit the determination of the exact conditions most suitable for each fuel.

An enormous number of boiler trials have been carried out, but most of them are mere individual tests of very little scientific value. Engineers have been too much under the impression that the evaporation depended chiefly on the type or proportions of the boiler, or the arrangement of the heating surface. But there are no obscure or complicated actions concerned in generating steam. Boilers of all types give nearly the same results, provided only proper conditions of combustion are secured. They may differ in cost, in durability, in convenience, but in efficiency they differ less than, I think, is commonly assumed. The following Table shows that boilers of extremely different types, with very different proportions of heating surface and very different rates of combustion, and even with different coals, have all reached evaporations of from 11 to 13 lbs. of water from and at 212° per pound of coal:—

BOILER TRIALS.

Type.	Ratio of Grate to Heating Surface.	Coal per Square Foot of Grate per Hour.	Evaporation from and at 212° per lb. of Coal.	Coal.
Cornish . . .	..	7·2	11·9	Welsh.
Lancashire . . .	1 : 36	22·9	11·2	Lancashire.
Galloway . . .	1 : 24	8·5	11·6	Anthracite.
Portable . . .	1 : 69	12·8	11·8	Welsh.
Tubular . . .	1 : 46	10·8	11·9	Anthracite.
Babcock . . .	1 : 38	8·9	11·8	"
Marine	1 : 34	22·4	12·9	Welsh.
"	1 : 50	25·5	12·5	Lancashire.
Thornycroft . .	1 : 70	7·7	13·4	Welsh.
" . . .	1 : 61	18·6	12·5	"

[1] Mr. Bryan Donkin was good enough to exhibit his form of bomb calorimeter at the Lecture.

Trials of Welsh and North Country Coal.

Between 1857 and 1870 several series of trials were made, partly at the instance of colliery-owners, partly under the direction of the Admiralty, to determine the relative value of Welsh and north country coal for generating steam. These trials extended over months and were laborious and costly, and they seem to me to have failed altogether to yield any useful result. In 1857 in trials carried on for many months, the result was obtained that Newcastle coal would evaporate 12·91 lbs. and Welsh coal 12·35 lbs. from and at 212° per pound of coal. Trials with the same boiler were then carried out under Admiralty direction by Messrs. Miller and Taplin. Their conclusion was that the Welsh coal evaporated rather more than the north country coal. A third series of trials were carried out at Cardiff, and in these the Welsh coal was found to be greatly superior to the north country coal. Finally, in 1881 to 1882, Mr. D. K. Clark carried out extensive tests obtaining from both coals evaporation of 12½ to 13¼ lbs. per pound of fuel. Mr. Clark concludes that when both coals are treated properly they are equal in evaporative power and equally smokeless. How came it about that these long and costly trials gave such uncertain and discrepant results? Quite similarly discrepant results, I believe, may be found in trials intended to determine the relative efficiency of different types of boilers.

In all these cases, the failure to obtain definite and concordant results was due to overlooking the fact that the chief waste, the chief cause of loss of efficiency in the action of a boiler is the heat carried into the chimney, and that this depends on simple conditions of air-supply. In none of these trials was the chimney waste measured, and hence the observers had no key to understanding the discrepant results they obtained. Variations of chimney waste are large enough to swamp all differences due to type of boiler or quality of fuel. The experiments failed to be conclusive from the want of a scientific perception of the importance of determining accurately for each fuel the minimum necessary air-supply, and for each trial the proportion of heat lost in the chimney.

Mulhausen Boiler-Trials of 1859.

The earliest boiler trials carried out in a completely satisfactory way were those made by the Société Industrielle of Mulhausen, in 1859.[1] The Society offered a prize to the maker of any boiler

[1] Bulletin de la Société Industrielle de Mulhausen, 1859.

which would evaporate 1,800 lbs. per hour at 75 lbs. per square inch pressure, and which would evaporate 9·1 lbs. of water from and at 212° per pound of Alsatian coal of not very good quality. In those trials the calorific value of the coal was determined, the ashes were weighed and analysed, the amount of air passing through the furnace was determined, the heat loss in the chimney measured, and a fairly satisfactory attempt was made to ascertain the dryness of the steam. With these data a proper balance sheet of the expenditure of heat could be drawn up. The efficiency of the three competitive boilers, when worked in the way shown to be best for each in preliminary tests, was practically identical and equal to about 70 per cent. With the coal used in these trials 130 cubic feet of air per pound of coal are chemically necessary for complete combustion. It was found that the reduction of the air-supply almost to this limit, and to a point at which there was definitely incomplete combustion reduced the chimney waste and increased the efficiency of the boiler. In two special trials, each of a week's duration, the evaporation was 9 lbs., with 331 cubic feet of air per pound, and 9·53 or 6 per cent. more with 247 cubic feet.

Some striking results, showing the dependence of boiler efficiency on air-supply, were obtained by members of the same Alsatian Society, at the works of Dollfus, Mieg and Cie. From several series of trials the following is selected:—

Date.	Coal Burned per Hour.	Cubic feet of Air at 0° and 0·76 m. per lb. of Coal.	Lbs. of Water Evaporated per lb. of Coal.
February to March, 1859.	Lbs. 330	206	5·86
	330	204	5·85
	330	165	6·30
	330	139	6·60
	330	120	6·66

Here the efficiency increases as the air-supply is diminished, even when it approaches the minimum chemically necessary. There are two ways in which decrease of air-supply tends to increase efficiency. The quantity of heated air reaching the chimney is less, and the velocity of the heated gases in the boiler flues is less, so that there is more time for heat-absorption.

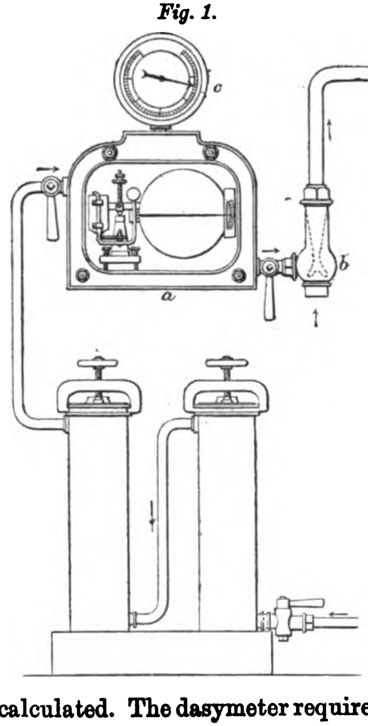
The determination of the air-supply to a boiler is not altogether

an easy operation. An anemometer was used in Alsace, and in suitable conditions it will give approximately accurate results. In recent trials chemical analyses of samples of the furnace gases have been made, and the amount of air supplied calculated from the percentage of CO_2. This method is accurate in principle, but the samples analysed are a very minute fraction of the total chimney discharge, and the samples may not be average samples. In some trials in which this method has been used, there are discrepancies in the ratio of the chimney loss, and the undetermined loss, chiefly due to radiation, difficult to understand. Neither anemometer nor chemical analyses is suited to serve as a means of regulating the air-supply in the ordinary working of a boiler. What is wanted is an instrument as easily read as a pressure-gauge and giving continuous indications.

THE DASYMETER.

The dasymeter, *Fig. 1*, invented by Messrs. Siegert and Dürr, of Munich, is a fine balance in an enclosed case, *a*, through which a current of the furnace gases is drawn. At one end of the balance is a glass globe of large displacement, at the other a brass weight. Any change of density of the medium in the chamber disturbs the balance. A finger on the balance moving over a graduated scale gives the amount of the alteration of density. An air-injector, *b*, draws the furnace gas from the flues, and it is filtered before entering the balance case. An ingenious mercurial compensator counterbalances any effect due to change of temperature or barometric pressure.

Fig. 1.

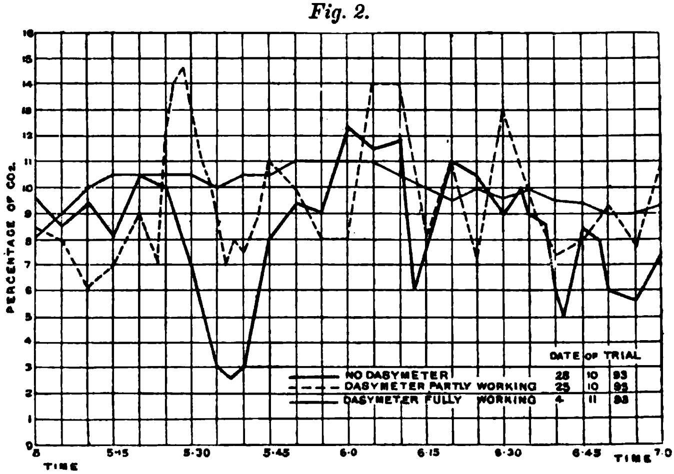


The dasymeter is usually combined with a draught-gauge, *c;* and an air-thermometer or pyrometer in the flue is required, if the amount of waste heat is to be calculated. The dasymeter requires

initially exceedingly delicate adjustment, and its indications must be checked from time to time by a Bunte's burette. It is set to read zero with pure air, and then any increase of density due to CO_2 is read as a percentage on the scale. When in adjustment it is as easy to read the percentage of CO_2 in the furnace gases as to read the pressure on a pressure-gauge. When the dasymeter is fitted to a boiler, the stoker has directions to adjust the supply of air so that the furnace gases have about 12 per cent. of CO_2. With practice he learns what alterations of the damper, or fire-door, or thickness of fuel on the grate are necessary, or whether a permanent alteration of grate-area is desirable. After a little time the percentage of CO_2 can be kept very constant.

The diagram, *Fig. 2*, shows records taken on three days at a boiler

Fig. 2.



provided with a dasymeter. The first curve taken on the 25th of October, and the second on the 28th of October, represent the great variations of CO_2 in the products of a furnace controlled in the ordinary way. The third curve, for the 4th of November, shows to what a great regularity the working of the furnace can be brought by a stoker who understands the indications of the dasymeter. The dasymeter is now largely used for boiler furnaces in Germany, and I am assured that in many cases a saving of 20 per cent. of the fuel has been secured. A similar instrument of somewhat different construction, invented by Mr. Arndt, is in use in France and Belgium.

The following short Table gives the results of two trials of a boiler of 1,076 square feet heating surface and 16 square feet

grate surface. The same coal and feed at the same temperature being used on both days. On one day there was a low dasymeter, on the other a high dasymeter reading:—

No. of Trial.	Duration.	Coal per 1,000 Lbs. of Steam.	Water per Hour per Square Foot of Heating Surface.	Steam Pressure.	Per Cent. of CO_2 by Dasymeter.	Chimney Loss.
	Hours.	Lbs.	Lbs.	Atmospheres.		Per Cent.
1	10	152·6	2·03	5·88	6·8	33
2	10	125·0	2·39	7·28	13·1	13

The air-supply is the one controllable factor in the working of a boiler furnace, and we have trusted far too long to the practical experience of boiler-makers and the common sense of stokers to regulate this important factor in boiler management. We do not trust the common sense of the stoker to regulate the boiler pressure or the water-level, and it is equally necessary, if economy is to be obtained, that he should be supplied with some means of ascertaining definitely whether his management of the fire is good or bad. I believe that in good and large installations, at least, it will come to be considered as necessary to have an instrument of the dasymeter type as to have a pressure gauge, and this, I think, may be regarded as a gift of science to the practical engineer.

Experiments on Steam-Engines.

It has been seen that Cornish experience pointed to the rule that very large ratios of expansion could be adopted with economy provided the conditions were those of Cornish engines. Expansion was generally used; but for a time with unfavourable results. Watt's rotative engines gave less than half the duty of Cornish engines.

If any one would like to see what a curious state of mind engineers were reduced to by the success of expansive working in Cornwall and its comparative failure elsewhere, I can refer them to a Paper by Mr. Palmer (1838) in the Transactions of this Institution.[1] Mr. Palmer found that while Cornish engineers claimed to have obtained a duty of 70,000,000 or even 100,000,000 per bushel of coal, no Boulton and Watt engine in other parts of

[1] "The Application of Steam as a Moving Power." By G. H. Palmer, M. Inst. C.E. Trans. Inst. C.E., vol. ii. p. 33.

the country was doing more than 28,000,000. He proceeds to a mathematical demonstration that with steam of atmospheric pressure it is impossible to obtain a duty with no friction and no loss of any kind exceeding 44,000,000, and that with steam of higher pressure used expansively, the duty must necessarily be less. He concludes that the Cornish results are altogether incredible. "Strong indeed," he says, "must be the evidence that ought to induce this Institution to sanction statements of duty more than double that of the best Watt engine, and still more surpassing the limits Nature has assigned to steam to perform." With the help of more accurate science, we have been able to actually obtain a duty about five times as great as that supposed to be the limit of possibility by Mr. Palmer.

Experiments on Marine Engines (Isherwood).

About the year 1860, Mr. Isherwood, chief engineer of the United States Navy, began a series of systematic tests of engines and boilers on a very large scale, and with resources only available in a Government establishment.[1] The trials were made with skill and determination; and the substantial accuracy of the results, startling as they were, has never been questioned. The service Mr. Isherwood rendered to steam-engineering deserves the fullest recognition; and if some of his opinions from his earlier Papers are quoted which he would not now defend, it is only to show what was the condition of opinion in the mind of a very advanced engineer thirty years ago.

Mr. Isherwood seems early to have doubted the economy of expansive working, which he says had long been an undisputed article in the creed of the engineer. By what he terms "a simple arithmetical calculation suited to the meanest capacity," he endeavours to show that the advantage of expansive working has been over-rated. In this calculation he makes a blunder, often reproduced since, in assuming that the whole work done in the cylinder, during admission as well as expansion, is due to heat obtained by condensation of steam. The error was unfortunate, because then and since it has diverted attention from the true cause of waste in the action of steam. Isherwood did find by his experiments a large cylinder condensation, but he was too acute to attribute the whole of it to work done. He pointed out clearly the action of water on the cylinder wall in abstracting heat during

[1] "Experimental Researches in Steam Engineering," vol. i. 1863, vol. ii. 1865.

exhaust, which would have to be supplied by condensation during admission. Further, he pointed out that priming water in the steam produces a loss greater than could be accounted for by mere abstraction of the heat in the priming-water from the boiler. In his earliest Paper he argues against the utility of jackets and against superheated steam, but experiment soon after led him to modify his conclusions on both these points.

All Isherwood's trials of large marine-engines showed that when expansion was extended beyond exceedingly small limits it caused not a saving but a waste. In his second volume he sums up his results as proving that when cut-off is earlier than 0·6 or perhaps even 0·7 of the stroke, the consumption of steam reckoned on the work done is increased. Curiously enough, this led him to attack the compound-engine. From the quantities in the Table of Experiments, he says, "It will be seen how useless in point of economic gain is the preposterous arrangement of steam-engine known as the double cylinder, Woolf, or Hornblower engine. . . . Opposed to these facts, the declarations of interested patentees and engine-builders must be classed in value with those set forth by quacks in advertisements of their nostrums." This is from a Paper dated 1865, and it is curious because Isherwood generally saw clearly enough the danger of drawing sweeping conclusions from narrow experimental premises.

Isherwood's experiments were made on large, low-pressure, slow engines, with large clearances, without jackets, and very great cylinder condensation. In these conditions, widely different from those of Cornish engines, any expansion, except to a very small extent, is uneconomical if regard is paid to indicated power, and still more, as Isherwood showed, if regard is paid to effective power.

TRIALS OF MICHIGAN. ISHERWOOD, 1861.

Cut-off.	I.HP.	Steam per I.HP.-Hour.	Steam per Effective HP.-Hour.
		Lbs.	Lbs.
0·92	301	40	43
0·70	211	35	38
0·44	204	33	36
0·30	134	35	39
0·25	118	34	39
0·17	74	37	44
0·09	61	46	61

The proper lesson from Isherwood's results was merely that certain conditions must be observed to secure economy in expan-

sive working. Unfortunately, more generally the conclusion was drawn that the Cornish results were not to be trusted, and that expansion was not economical, and Isherwood's own language lent authority to the least accurate view of his results. To obtain greater insight into the true action in the cylinder, and to find a reconciliation of the Cornish and American tests, experiments of a much more refined character were wanted and insight due to wider scientific knowledge.

The Physical Properties of Steam (Regnault).

No useful progress could be made with a theory of the steam-engine, no accurate reduction even could be made of the results of engine tests, without exact determinations of the relations of pressure, temperature, volume, latent heat, and liquid heat of steam. It was fortunate, therefore, that about 1840, Regnault[1] obtained the means from the French Government to make a series of researches on the physical properties of steam with splendid instrumental appliances. He wisely carried out his determinations over a very wide range of conditions, and spared no labour or trouble in attaining accuracy. Regnault's results were of the greatest importance as a foundation for accurate study of the steam-engine.

The Foundation of Thermodynamics (Carnot and Joule).

The next important step was the discovery of the equivalence of heat and work. Joule's investigations began with an attempt to improve Sturgeon's magnetic engine. He was so led to consider motive-power problems from the engineer's stand-point, as a question of duty, or of something obtained for something expended. He ascertained the amount of electric current produced by the chemical combustion of a given amount of zinc, and comparing his results with those obtained in good steam-engines, he concluded that, making the largest allowance for possible imperfections of his magnetic engine, it was never likely to be a rival in economy to the steam-engine. That was a negative but a useful result. It closed one direction of useless endeavour only too likely to attract the inventor.

One of the effects of electric action which Joule noticed, was the heating of his conductors, and it was to the measurement of this heating effect he next addressed himself. The heat developed in

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[1] Regnault, Mémoires de l'Académie, tom. xxi. Paris, 1847.

the conductor by the electric action due to elements combining in the galvanic cell, was found to be identical with that which would be generated by the direct combustion of the same elements. Finally he came to consider the relation between the mechanical work expended in driving a magneto-electric machine and the heat developed in the external circuit of the machine. He concluded that for 838 foot-lbs. expended, a pound-degree of heat was generated. Later experiments corrected this value, but the discovery of the equivalence of heat and work was made.

Here, for a short time, Joule was misled by his own discovery. Examining the case of the steam-engine, he found that of the heat generated in the boiler furnace less than one-tenth was actually converted into work. On that he too hastily assumed that this was a measure of the remediable imperfection of the steam-engine. It was not till six years after that he understood the physical limitations to the conversion of heat into work. The motivity of heat, or its capability of conversion into work, depends on local conditions. To increase the proportion converted in the steam-engine, except so far as decreasing subordinate losses is concerned, it would be necessary to remove it to another planet where more favourable conditions for heat-conversion exist.

As early as 1824, twenty years before Joule's discovery, Sadi Carnot, in a remarkable pamphlet on the Motive Power of Heat, demonstrated the fundamental principle that the amount of work obtainable from any given quantity of heat cannot exceed a quantity, proportional to the fall of temperature. Unfortunately, adopting, though with hesitation, the view held in his time that heat is material and indestructible as heat, he coupled with his true principle the false corollary that all the heat entering an engine is discharged in the condenser. Joule in 1845 found this principle of Carnot, and looking to the corollary as essential, supposed the principle itself to be false. He failed to perceive that Carnot's principle was the essential supplement to his own discovery, and that it showed why the apparent efficiency of the steam-engine is so low. It took six years before Joule's and Carnot's principles were reconciled, and for three of them even Lord Kelvin refused to accept Joule's discovery because it apparently conflicted with the principle of Carnot.

Permit me a very short digression. In popular writings nothing is commoner than to find the efficiency of electric machinery and of steam machinery contrasted to the great discredit of the latter. The dynamo, it is said, has an efficiency of 90 per cent. to 95 per cent., the steam-engine an efficiency of only 10 per

cent. What a barbarous machine, after all the labour of a century, the steam-engine must be! The comparison is generally made by an electrical engineer, and the first reflection which occurs to one is that of all people the electrical engineer should be the last to abuse the steam-engine; for, whatever may be the case in some future century, at present the dynamo is absolutely dependent on the steam-engine. Without the steam-engine, the dynamo would be a useless mass of metal and wire. But passing over the moral aspect of the question, the ingratitude of the electrical engineer, the comparison is an unfair one, and shows a want of apprehension of that important law of the motivity of heat which is one of the two fundamental laws of thermodynamics. Heat-energy is undirected or mob-energy. It lies in the nature of the terrestrial conditions in which use has to be made of it, that only a fraction is convertible into directed or mechanical energy. The task of the steam-engine is to do its best with the fraction which is convertible, and in that point of view it is not an inefficient machine. The dynamo has a much easier task. Energy is supplied to it in its directed or wholly convertible form, and naturally in transforming one kind of directed energy into another kind of directed energy only a small fraction need be wasted.

The Founders of the Rational Theory (Rankine, Clausius, Zeuner).

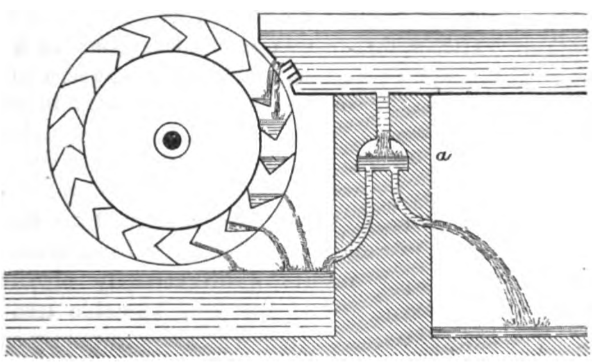
The impetus given to the study of Thermodynamics by the discovery of Joule and the perception of the fundamental importance of Carnot's theorem was enormous. Heat-problems could now be brought out of the region of mere empirical solutions, and treated from the rational standpoint of an exact science, and the steam-engine as the most important example of heat transformation attracted at once the attention of scientific men of commanding intellectual ability. In a very few years Rankine and Clausius had built up a strictly rational mathematical theory of the steam-engine, and a little later Zeuner carried further the analysis of some of the more subordinate details. The theory, with one exception to be referred to presently, took account of all the actual conditions under which steam is used, and furnished exact rules for the relation of steam expended and work done for all arrangements of the actual steam-engine practically adopted. Subject to only one restriction of importance, the rational theory would have given the means of determining by nearly exact calculation the relative economy of different types of engines, the

precise advantage in any given case of any particular ratio of expansion, the loss due to clearance and other questions of that kind. No physical theory of any machine was ever constructed more complete or on less exceptionable data.

It was just at this time that the experiments of Isherwood were published, and a comparison of experimental results and theoretical calculations showed directly a very large discrepancy. The steam consumption in some trials was 30 per cent., 40 per cent., or 50 per cent. more than it should have been in the assigned conditions of working, according to the rational theory. Some action of quite governing importance had obviously been neglected in the theoretical analysis.

A rough illustration will perhaps make clear where the defect of the rational theory lay. Suppose a good water-wheel, *Fig. 3*, driven

Fig. 3.



by a fall of water. The mechanical action of the water is of a simple kind, and a theory is easily constructed which would give the relation of the water expended and the useful work done. Now suppose that, unknown to the constructor of the theory, there existed a large leakage from the head race to a reservoir *a* in the supporting walls. Obviously the water expended would be greater than the calculated expenditure. The error of the calculation would not be due to any defect of the theory of the water-wheel, but to an extraneous and additional action which had not been taken into account. There was a neglect of a very similar kind in the rational theory of the steam-engine, a leakage of heat treated as negligible in the theory which is in fact far too large to be treated as negligible in the practical working of the engine. Heat leaks into the cylinder-wall during admission and leaks out

during exhaust. Rankine and Clausius and Zeuner were well aware that the operation of the steam in the engine has to be carried out in a metallic cylinder capable of absorbing and giving up heat. But the conditions in which this exchange of heat occurs are complicated and very difficult to include in a mathematical analysis. They left the heat exchange with the cylinder-wall out of the analysis as a matter which could be allowed for by some empirical coefficient. No doubt they altogether under-rated the enormous facility of heat exchange which arises out of the contact between a conducting cylinder-wall and a vapour in a condition of the greatest instability and liable to condense or evaporate on the slightest change of thermal condition.

The Experimental Theory (Hirn and the Alsatian School).

A year or two before Isherwood began his experiments, an Alsatian engineer, Hirn, had discovered and measured cylinder condensation. Hirn's father was artistic designer to a factory where printed calicoes were made, and Hirn was at first in charge of the chemical laboratory of the factory. His first independent commercial adventure was in 1855, when he introduced mineral oil obtained in Alsace for lubricating purposes. One of his earliest scientific Papers was an account of researches on the friction of lubricated surfaces, which was refused by more than one scientific society, and since its publication has remained little noticed. In this Paper results quite recently obtained are anticipated, and it is still one of the most valuable treatises on friction. The chief interest of Hirn's life was in purely scientific research, especially investigations of some of the most abstruse physical problems. The study of the steam-engine, begun with a view of verifying Joule's discovery, was merely an interlude in a series of investigations, mostly dealing with more abstract departments of science. But Hirn formed a school of engineers devoted to the carrying out of experiments on the steam-engine. He formulated the methods of engine-testing adopted almost without change ever since. He brought to the analysis of the results an extremely acute intellect. He was the first to realise that the complexity of the actions in a steam-engine was so great that a purely rational theory was impossible, and that the engine could only be studied usefully by (to use a phrase of Professor Cotterill) checking theoretical conclusions step by step by reference to experiment.

Joule's discovery attracted Hirn's attention, and he set to work

in 1854 to verify by an exact engine-test, whether the difference between the heat received by an engine and discarded in the condenser was the equivalent of the work done. His two most important memoirs relating to the steam-engine are, a memoir on the utility of steam-jackets in 1856, and another on the use of superheated steam in 1857.[1] In these researches he devised a method of accurate engine-tests, involving the measurement of all the quantities of heat received by or rejected from the engine, which, with hardly any change at all, is the method of accurate engine-testing adopted ever since. Under his influence and direction, engine-tests were carried out in Alsace for many years, and the results exactly analysed. It may be recalled that the admirable series of engine-tests, the first tests in which the heat quantities were accurately measured in this country, which were made by Mr. Mair Rumley, and described in three Papers on Independent Engine-Tests in the Proceedings of this Society in 1882, 1885 and 1886, were trials carried out strictly in accordance with Hirn's methods.

As with Lord Kelvin, so with Hirn. It was the recognition of an apparent conflict of Joule's discovery with Carnot's law which first attracted his attention. It was the attempt to determine whether part of the heat supplied to an engine disappeared as work which determined the form of his trials. His experiments of 1854 showed that "heat in a steam motor is not only dispersed, but actually disappears, and the power obtained is exactly proportional to the heat which disappears as heat to reappear as motive power." Some rather later and more careful experiments enabled him to verify Joule's equivalent by the actual results of a large engine-test to an accuracy of about 1 per cent.

Hirn's heat measurements in the engine trials of 1854–6 showed the important and even unaccountably large influence of the steam-jacket on the steam-consumption. Its effects could not in any way be explained as merely the arrest of external radiation, for the decrease of heat losses in the engine proved to be larger than the heat yielded to the cylinder by the jacket. It was in studying the action of the jacket that Hirn came to perceive, and before anyone else, to directly measure the initial condensation of steam in the cylinder.

The following are some results obtained a few years later by Hirn and Hallauer on a Corliss engine. Working without a jacket, the initial condensation was 62·3 per cent. The proportion

[1] "Mémoire sur l'Utilité des enveloppes à vapeur," Bulletin de la Société Industrielle de Mulhouse, 1856; "Mémoire sur la Théorie de la surchauffe dans les Machines à vapeur," Bulletin, 1857.

of water in the steam at release was 41·4 per cent., so that 20·9 per cent. at least was re-evaporated during expansion. Working with a jacket, the initial condensation was 46·5 per cent., or 16 per cent. less than in the unjacketed trial. Further, the proportion of water present at release was only 15·3 per cent., so that 31·2 per cent. had been evaporated during expansion. Hence the gain from the jacket in those cases where it produces a considerable effect arises in two ways. The prejudicial initial condensation is considerably diminished, and more heat is given back from the cylinder wall during expansion when the temperature in the cylinder is higher and when it is partially used in doing work, and less during exhaust when the temperature is lower and when it does no useful work.

The discovery of initial condensation and the proof of the powerful action of a small amount of heat transmitted from the jacket both pointed to the conductivity of the cylinder-wall as the cause of the large waste of steam which the constructors of the rational theory had neglected. The cylinder is cooled during expansion, and still more during exhaust by an action analogous to internal radiation to the condenser. Before any work can be done in the next stroke, the wall has to be re-heated by condensing fresh steam. The extreme facility with which steam yields or abstracts heat by condensing and evaporating, accounted for the rapidity of the action. The magnitude of the condensation increases with the range of temperature to which the cylinder wall is subjected. It is larger in condensing- than in non-condensing-engines, and larger with high ratios of expansion.

HIRN'S EXPERIMENTS 1873–75. THERMAL UNITS PER STROKE.

—	Saturated.		Superheated.		
Ratio of expansion	4·0	7·0	2·0	4·0	7·0
Heat in dry steam admitted	144·1	101·7	110·2	119·7	87·5
" " entrained water or as superheat	0·3	0·3	6·2	7·4	3·5
Heat carried to engine	144·4	102·0	116·4	127·1	91·0
Heat in condensed steam discharged from condenser	7·5	5·1	6·0	5·7	4·1
Heat expended per stroke	136·9	96·9	110·4	121·4	88·9
Heat accounted for in work done and radiation	16·6	12·7	14·6	17·7	13·5
Difference, or heat which should be found in condensing water	120·3	84·2	95·8	103·7	73·4
Actual heat found in condensing water	121·4	84·0	96·5	104·6	73·5

HIRN'S EXPERIMENTS 1873–75.

——	Saturated.		Superheated.		
Ratio of expansion . . .	4	7·0	2	4·0	7
Per cent. of water in steam admitted	1	0·8	0	0·0	0
Per cent. of water at end of admission	31	37·0	0	6·5	25
Per cent. condensed during admission	30	36·0	0	6·5	25
Per cent. of water at release . .	25	35·0	13	12·0	21
Per cent. re-evaporated during expansion	5	1·0	..	..	4
Per cent. condensed during expansion	..	..	13	5·5	..

Some time ago I ventured to say that there was no trustworthy engine-test, which showed that the consumption of steam with a jacket is greater than without a jacket. I believe that is still true, but undoubtedly the economy due to the jacket varies in different cases from 30 per cent. to very nearly zero. Roughly, the jacket is more useful with small engines than with large; with slow engines than with fast engines; but all this amounts to little more than saying that the jacket is most useful in those cases where the initial condensation is largest. Just in proportion as the engine, whatever its type, is of the highest class and most scientific design, the jacket is less useful. No one probably designed better simple engines than Corliss, and Corliss did not use jackets. In an experiment by Delafond on a large Corliss engine at Creusot, the jacket effected an economy of only 2 per cent. The same rule holds with compound engines. Hirn found an economy of 25 per cent. due to the jackets in a Woolf engine, tested in 1855, but since then the compound engine has been improved, and the advantage of the jacket is less. Professor Witz[1] made very accurate experiments with a large compound engine of about 600 I.HP., provided with jackets both to cylinders and receiver. The trials were strictly comparable, the pressures, temperature ranges, and total power developed being nearly the same. The total condensation in the jackets was 12 per cent. of the steam used, so that the jackets were not inactive. Yet the absolute saving of steam due to the jackets was only 4 per cent., or, allowing for heat saved by returning the jacket drainage to the boilers, 6·6 per cent.

It is perhaps probable that as the temperature range in the

[1] Witz, "Enveloppes de Vapeur." Lille, 1893.

cylinder is diminished by compounding, the temperature gradient from the jacket to the interior of the cylinder is diminished, and the rate of transmission of heat decreased. It appears, then, that as engines are better designed, the jacket is of less use, and it is not by means of the jacket that the waste due to cylinder condensation can be got rid of, or the highest economy of which the steam-engine is capable reached.

The jacket reduces but it does not prevent initial condensation. Hirn looked for some more powerful way of heating the cylinder-wall without causing condensation; he found it in superheating. He constructed in 1855 a superheating apparatus in the flues of the boiler at Logelbach, which still exists. The experiments with superheated steam were carried out between 1855 and 1856, and showed clearly the effectiveness of the method in reducing condensation. Superheating came largely into use in the years 1860–70 in this country in marine engineering practice, having been introduced here by John Penn. In every case in which it was used an economy of coal was realised. Generally the economy amounted to from 15 per cent. to 20 per cent. It was ascertained that this was due strictly to economy of steam, and not to the utilization in the boiler of heat previously wasted. But the use of superheated steam in this country was gradually abandoned, partly, no doubt, from some practical difficulties, but chiefly, I believe, because practical engineers had no clear idea why superheating should produce so large an economy, and they were not indisposed to abandon a complication the action of which they could not satisfactorily explain to themselves.

In Alsace, superheating has never been entirely abandoned, and during the last ten years hundreds of boilers have been supplied with superheaters. So far as I can ascertain, no difficulty arises in using steam superheated to 500° F., and in good and large engines the steam-consumption is reduced, when the superheating amounts to 100°, by 15 per cent. on the average. I have no doubt myself that superheating will be largely used again. The practical difficulties exist, but they are not insuperable.

No possible improvement of the steam-engine, of which we have any knowledge at this moment, offers anything like so great a chance of important economy as the re-introduction of superheating, and especially of superheating to at least 100° or more above the saturation temperature of the steam. I obtained in Alsace, on a very good 500-HP. compound mill-engine, with jackets and every appliance for economical working, an economy of 15 per cent. Mr. Mair Rumley has fitted a superheater to a Babcock

boiler supplying a triple engine, and has obtained an economy of 10 per cent. Mr. Willans made four experiments on a simple condensing engine with saturated steam, and four corresponding experiments with superheated steam. The mean amount of superheating was only 35° F.; but a mean economy of 8 per cent. of steam was obtained in the superheating trials. In these cases the economy is economy of steam, and therefore is not due to any increase of boiler surface or increase of efficiency in generating the steam. Lately Professor Schröter, of Munich, has been experimenting with a small special compound condensing engine of only 60 I.HP. running at the moderate piston speed of 380 feet per minute, and with the not excessive boiler pressure of 165 lbs. per square inch. The H.P. cylinder is not jacketed. The L.P. is jacketed with receiver steam. In this case, in a tube superheater of a rather special construction in the uptake of the boiler, the steam is superheated to 670° F., or nearly 300° above the saturation temperature corresponding to the pressure. In two trials of six and eight hours' duration, periods quite long enough for accurate determination of results with so accomplished an observer as Professor Schröter, the consumption of steam was only 10·2 lbs. per I.HP. hour, and the consumption of German coal of moderate quality only 1¼ lbs. per I.HP. hour. The steam consumption is the lowest on record for any engine of any type or size, and is very remarkable for so small an engine.

It is often argued that as very little heat is required to superheat steam it cannot produce much effect. The answer is that a small amount of heat rightly applied in preventing initial condensation produces a disproportionately large effect. That is consistent with the strictest principles of thermodynamics. In the Schmidt engine only 8 per cent. of the heat was used in superheating the steam, and to this 8 per cent. the remarkable economy is due. In a steam-jacket acting well, about 12 per cent. of the steam used is condensed, and to this 12 per cent. the advantage of the jacket which often reduces the amount of steam used in the cylinder by 20 to 30 per cent. is due. But the heat from a jacket is much less efficiently applied than the heat taken direct to the interior of the cylinder by superheated steam and used primarily in maintaining the temperature of the admission surface. Further, the quantity of superheat brought into the cylinder in a given time increases with the speed of the engine while jacket-heat diminishes in effect as the speed is greater. The action of the superheated steam is shown clearly enough on the indicator diagrams. In my own trials in Alsace the wetness of

the steam at cut-off in the H.P. cylinder with jacket, but without superheating, was 35 per cent.; with steam superheated 100° it was only 15 per cent. In the trial with the Schmidt engine there was no moisture at cut-off in the H.P. cylinder, and the steam remained dry nearly to the end of the stroke.

CONFLICT OF THE RATIONAL AND EXPERIMENTAL THEORIES (ZEUNER, HIRN AND HALLAUER).

On the appearance of Isherwood's researches in 1863, the discrepancy between the rational theory and the results of experiment was recognised by Rankine and others. But the conditions of cylinder condensation are so complex that for a long time the more theoretical writers practically ignored both Hirn's and Isherwood's results. Zeuner, perhaps, had pushed the rational theory to the furthest limit of detail and with the greatest insight into practical conditions. But it was not till 1881 that he began to explicitly admit the largeness and importance of the condensing action in the cylinder. Zeuner then was disposed to attribute initial condensation to the presence of a permanent and not inconsiderable mass of water in the clearance space of the engine. No doubt it is simpler analytically to deal with the thermal changes of the steam plus a given mass of water than with the thermal changes of steam, water and a varying area of solid cylinder-wall. In opening a discussion with Hirn in 1881, Zeuner wrote that if the presence of water in the clearance space was conceded the Alsatian calculations would be greatly shaken and "the enormous influence which they attributed to the cylinder-wall would in future be attributed in part, perhaps chiefly, to the water in the clearance space." He thought it conceivable that in certain cases the whole of the initial condensation was due to water in the clearance space. There thus arose a rather angry controversy which has been summed up in the question, "Is it water or iron?" I do not know that this controversy has been as yet completely decided, or that perhaps an absolute decision is possible. I cannot help thinking that Hirn, with the clearness of view due to his experimental work, had on the whole the best of the controversy, and I do not know that anything better or more instructive can be said than the words in which he finally summed up his position.[1] "We recognise," said he, "that the interpretation of the Alsatians differs from that of M. Zeuner, not at all in that

[1] "Réfutation de la Seconde Critique de M. Zeuner," Bulletin, 1882.

it denies the possible presence of water in the cylinder (we are not so hydrophobic), but in that it admits that that water, varying in quantity, is presented only temporarily, is carried away and renewed stroke by stroke, and acts chiefly as the medium between the steam and the cylinder-wall. In the Alsatian explanation, the action of the water raises the thermal action of the sides. In Prof. Zeuner's view the water is permanently present and acts independently of the cylinder sides."

We may note that Mr. Donkin has been able to show, by direct thermometric observations, a considerable fluctuation of temperature in the innermost layer of the cylinder-wall, in the period of a revolution, and that, more lately, Professor Carpenter, of Sibley College, has obtained photographic records of the fluctuation of temperature by using a thermopile and a recording galvanometer.

Recent Systematic Experiments (Willans).

It has been quite impossible in this lecture to do more than select one or two of the most important of the experimental investigations during the last fifty years. But I should not like to omit all reference to the two series of experiments of the late Mr. P. W. Willans.[1] Mr. Willans' work is, no doubt, well known to all steam-engineers, and needs no detailed description. However purely practical the object Mr. Willans had in view, his experiments were made in the true spirit of scientific research. No trouble was too much to secure accuracy to the last decimal, no possible cause of error was so trivial that its investigation was reckoned unnecessary. A few experimenters—Isherwood, Gately and Kletsch, and others—had made experiments on a methodical system, varying a single factor at a time. Willans carried out the method of experiments in series, on a scale which, till he proved that it could be done, no one would have supposed possible. There is a series of non-condensing, and a series of condensing trials; in each there are trials of simple, compound, and triple engines; and for each of these again, trials with initial pressure varied, with expansion varied, and with speed varied. The results, tabulated in the clearest way, form a quarry of scientific data, but at present in the main an unworked quarry. Perhaps that statement will seem surprising, and of course I am expressing only my own view, for which I claim no infallibility. What Mr. Willans might have

[1] Willans, "Economy Trials of a Non-condensing Steam-Engine," Proc. Inst. C.E., vols. xciii. and xcvi.; "Steam-Engine Trials," Proc. Inst. C.E., vol. cxiv.

done had he been spared, it is impossible to say. He had the most active mind and the widest experience devoted perhaps at any time to the study of steam problems. But so far as his Papers go, they are confined to the description of his experiments. On the causes and laws of cylinder condensation, there is little in his Papers except some acute observations on special anomalies observed. Willans himself said that "he was unwilling to suggest any theory to account for the various results shown in these Tables." But without a theory they remain as individual results for a particular engine, of a particular size and type, in particular conditions. Without a theory no one can use these results, say, to predetermine the steam-consumption of any other engine of a different size, or in other conditions. What they do make clear is that the variation of steam-consumption in different cases is exceedingly complex, so complex as sometimes to seem capricious.

Let me protest as strongly as possible, again with the reservation that I am stating my personal view, against the tendency to suppose that the great work of Willans can be summed up in a so-called Willans law, or that that law, handy as it may be for practical steam-engineers, is more than a quite subordinate part of Willans' work. The Willans law is nothing more than the empirical descriptive statement that the relation of total steam-consumption and indicated or effective HP. can be very approximately expressed by a linear equation, for the case of an unjacketed engine working with a fixed cut-off. Further, nothing is done in Willans' Papers to fix what is the linear equation for any given engine. So far as those Papers go and until some kind of theory taking account of initial condensation is discovered, we can only find the relation of steam-consumption and HP. for any given engine by making two accurate trials of the engine itself. The Willans law leaves us in regard to any given engine in the same position as an astronomer with a new comet. When the comet has been observed for a sufficient period and some of its positions fixed, a probable orbit can be calculated. The straight line law leaves the steam-consumption of a new engine as unknown as the elliptic law the orbit of a new comet.

Willans' law is being used, I am afraid, by many engineers with little discretion. I find engineers who assure me that they plot tests of automatic expansion engines in straight lines and that they find nothing wrong. But if Willans was right that the relation of steam-consumption and HP. for a throttled engine was linear, then it is demonstrable that the relation for an engine with

varying expansion or varying speed must be of a more complex kind. I am driven to conclude that as to steam-consumption with varying load, engineers are content with rough approximations.

Willans himself says nothing whatever as to any possible rational basis for the Willans law. He put it forward purely as the result of plotting his experiments. Later, Captain Sankey showed that the total steam-consumption of an engine working adiabatically with fixed ratio of expansion would also follow nearly but not exactly a straight line law, if all clearance losses, radiation and exhaust waste and back pressure loss were neglected. The adiabatic law is inconvenient in forming an equation for the relation of steam-consumption and HP., and the actual expansion curve of an engine is much more nearly a hyperbola than an adiabatic, because the steam receives heat from the cylinder-wall. If we assume hyperbolic expansion (and really so far as the area of the diagram is concerned, it matters little what law of expansion is assumed) it is easy to find a formula for the total steam-consumption of an engine, working without clearance loss or exhaust waste. I have found such a formula and plotted the results both for a condensing and a non-condensing engine, in the diagram, *Fig. 4.* It will be seen that the lines (full lines) plotted are not exactly but very nearly straight lines. That carries us a certain way, but it is an enormous jump to assume without examination that the steam wastes in the engine, amounting to from 20 per cent. to 50 per cent. of the steam used and arising from causes of the most complex kind, depending on the volume of the clearance, the action of the cylinder-wall, the loss of the toe of the diagram, the waste expansion between the cylinders, and other causes of loss, that this also can be expressed as a simple linear function of the HP.

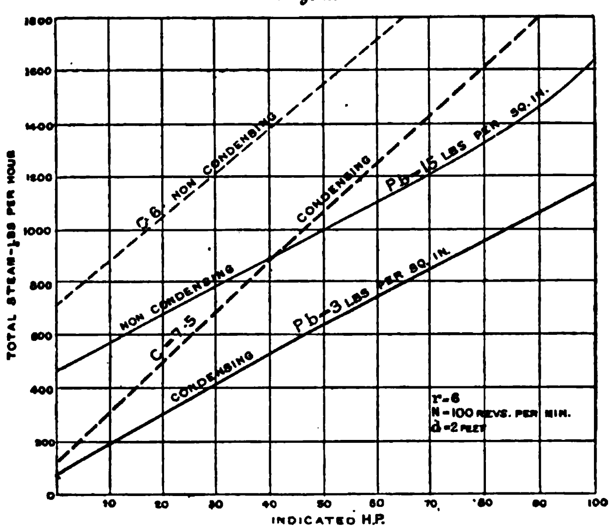
Now in the first edition of his "Treatise on the Steam Engine," which appeared in 1878, Prof. Cotterill had seriously attacked the problem of cylinder condensation from the theoretical side. After Hirn, he was one of the first to recognise that the action of the cylinder-wall was a superficial action, and further, what had not before been recognised, that it depends in some way on the admission-surface reckoned per lb. of steam used. He therefore studied the action in the cylinder of a plate of metal so thin that it would follow exactly the temperature changes of the steam. On comparing the results of this assumption with the data obtained in engine-tests it appears that the temperature-cycle in the cylinder-wall cannot be, except in limiting cases, identical with the temperature-cycle of the steam, and this introduces a complication.

Nevertheless, Prof. Cotterill found it possible to give a partly rational, partly empirical formula for cylinder condensation.[1] The ratio of the water present to steam present at cut-off is

$$y_1 = C \frac{\log_e r}{d\sqrt{N}},$$

where C is a constant for any given engine and has only a limited range of values for engines of widely different sizes and proportions. But according to this formula, for unjacketed simple engines the initial condensation has a fixed ratio to the steam

Fig. 4.



INITIAL PRESSURE VARIED.

present at cut-off. In the diagram, *Fig. 4*, lines for steam present at cut-off are given (full lines), calculated in the manner already described. Above these has been set up the condensation by Cotterill's law, and the total steam-consumption at various loads is then given by lines (dotted) very nearly straight and closely agreeing with Willans lines.

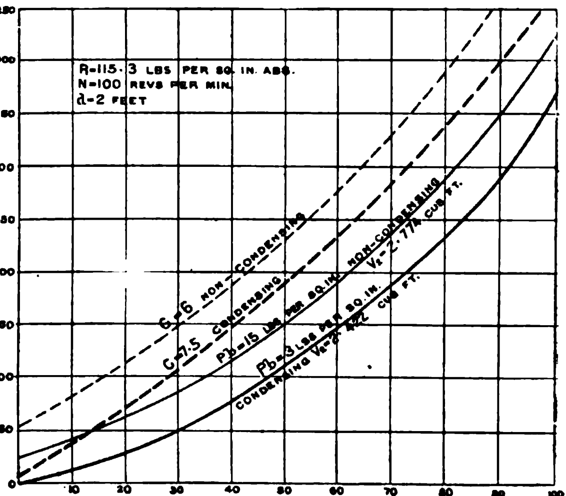
But now if Cotterill's formula is trustworthy for determining the condensation in a throttled engine working at various pressures, there is no reason why with the same restrictions as before

[1] Cotterill, "The Steam Engine," 1890, p. 339.

it should not apply to an automatic expansion engine. Another diagram, *Fig. 5*, shows first the curves of steam-consumption (full lines), calculated by the formula mentioned before, which gives the steam present at cut-off, and above them curves of total steam-consumption (dotted) obtained by adding values of condensation calculated from Prof. Cotterill's formula.

The curves on the two diagrams agree well with Willans' results, and they differ from Willans lines in being obtained entirely by calculation without experimenting on the engine. It would not be right to make too much of the coincidence, but I thought it would be interesting to show that theory and experi-

Fig. 5.



EXPANSION VARIED.

ment converge. A good deal has yet to be explained, but the discussion in Prof. Cotterill's treatise has done more than anything else to throw light on the conditions which promote or hinder cylinder-condensation, and on the means useful in securing economy of working.

I should have liked, had time permitted, to mention another direction of experimental research which promises to be useful.

The purely dynamical actions in the engine like the thermal actions have proved too complex for any purely rational treatment. Here also it is necessary to check the results of theory step by step by reference to experiment. The total friction of engines

has been determined by various methods and proves to be more nearly independent of the load than the earlier writers assumed. Hirn converted the beam of his engine into a flexion dynamometer which drew a diagram of the effective work of the engine, and some method of this kind might be revived with much advantage. Prof. Carpenter and Mr. Preston have attempted experiment on the friction of different parts of the engine, with the striking result that the crank-shaft bearings absorb nearly half the frictional work of the engine and the piston about one-fourth. Mr. Ransom has studied experimentally the action of governors, and lastly Prof. Dwelshauvers Dery has attempted a general experimental study of all the dynamical actions which affect the motion of the engine.[1]

Since 1845 purely scientific men, scientific experimenters, and practical engineers have all been engaged in the study of the steam-engine. I do not believe that any one of the three can claim all the credit for the improvement of the steam-engine to the exclusion of either of the others.

What has been achieved is shown in the following Table:—

RECENT ENGINE TESTS. LOWEST STEAM CONSUMPTION.

Kind of Engine.	I.HP.	Boiler Pressure.	Piston Speed.	Steam per I.HP.-hour.
		Lbs. per Sq. In.	Feet per Minute.	Lbs.
Simple—				
Sulzer	284	87	372	18·4
Corliss	137	62	..	17·5
Compound—				
Dujardin	548	90	570	13·46
Sulzer	247	85	493	13·35
Wheelock	590	160	612	12·84
Leavitt	643	135	371	12·16
Bollinckx	305	91	479	12·19
Triple—				
Willans	30	170	384	12·74
Sulzer	615	141	516	11·85
Allis	574	120	203	11·68
Compound superheating—				
Schmidt	76	180	380	10·17

Representing perhaps rather the scientific than the practical interest, I venture to claim that the mathematical and physical

[1] Étude expérimentale dynamique de la Machine à Vapeur." Paris, 1894.

researches of which I have tried to give an account have had an influence on the practical business of the engineer.

Of a few only of the more salient points in the history of the steam-engine has it been possible in this Lecture to give even a brief and imperfect account. The omissions I know are almost innumerable. I can only hope that no fault or omission of mine obscures the lesson that science and practice go hand in hand.

Sir ROBERT RAWLINSON, K.C.B., President, said the members had listened with great attention to Professor Unwin's lecture upon the interesting question of how most profitably to deal with steam. It was obvious, from the deep attention paid to the lecturer that the facts laid before the audience would be treasured up and applied to future purposes. He begged to propose a hearty vote of thanks to the lecturer.

Mr. W. H. PREECE, C.B., Vice-President, had great pleasure in seconding the proposal that the President had made. An extremely interesting discourse had been given, which the lecturer had well maintained on the theme with which he had started and had finished—the theory that science and practice should work together hand in hand. In the historical comments Professor Unwin had made, he had pointed out how necessary it was to be very careful with regard to the conclusions to be drawn from facts that appeared before one's eyes. Engineers were, as it were, swimming in a sea with which they were not thoroughly acquainted, and which they could not sound. Although Palmer in days of old might have drawn what now appeared to be ridiculous conclusions, it might be that twenty-five or thirty years hence other people might get up and speak of the absurd conclusions that were brought before the Institution of Civil Engineers in 1895 by no less an authority than Professor Unwin. The present, of course, was not an occasion for discussion, but if the occasion arose, he would be tempted some day to defend the morality of the electrical engineer. Professor Unwin had, however, saved him that necessity, for at the commencement of the Lecture he had referred to the influence of the working of central electric-lighting stations upon the economy of the steam-engine, and the last portion of his address bestowed a well-deserved tribute upon one of the ablest engineers of the present day, whose whole attention was devoted to endeavouring to perfect the steam-engine solely to aid the endeavours of electrical engineers. He had great pleasure in seconding the vote of thanks, and he would add that no one would rejoice more than

Mr. James Forrest that the lecturer had so well fulfilled his task.

The resolution was carried by acclamation.

Professor UNWIN, in reply, begged to thank the members for the very kind manner in which they had received his Lecture. The preparation of a general Lecture of the kind he had given always filled him with a sort of dismay. It was not possible to treat a large subject in so short a time without omitting much. But however imperfectly one might fulfil such a task the kindness of audiences relieved one from much of the difficulty.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 2676.*)

(*Abstract.*)

"The New Papaghni Bridge on the Madras Railway."

By Harry James Thompson, M. Inst. C.E.

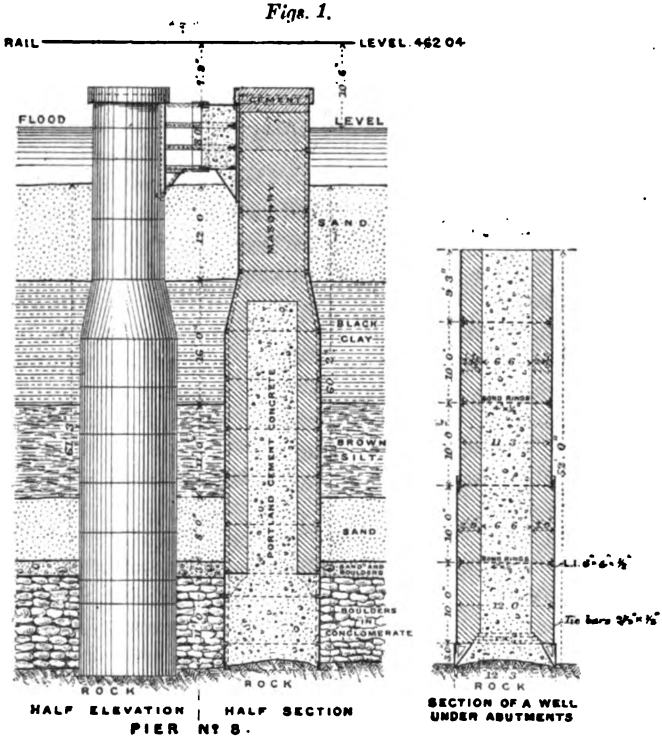
The Papaghni river was originally bridged by the Madras Railway in 1863, by means of nineteen spans of 70 feet each, centre to centre, formed of plate girders, continuous over two openings. The piers were of screw-pile construction. In an exceptionally heavy flood in 1874, four piers and two sets of girders were swept away, but the bridge was repaired and remained in use till the 1st July, 1892, when the new bridge was opened for traffic. The new bridge is parallel to the old one and is situated at a short distance above it. It consists of fifteen spans measuring 140 feet, between the centres of the piers, and is similar in design to other bridges recently rebuilt on the same railway, of which one (over the Chittravati River) has been described[1] and illustrated by Mr. E. W. Stoney, M. Inst. C.E.

Abutments.—Each abutment is carried on seven masonry wells, 12 feet in external diameter and 6 feet 6 inches in internal diameter, built on wrought-iron curbs. The Author was directed to use external tie-bars of 4 inches by ½ inch flat iron, in order to avoid the disadvantage attending the ordinary round tie-rods carried up through the masonry, that they start a line of fracture in case any obstruction is met by the curb. It was found, however, at the eastern abutment that these external tie-rods were apt to be torn off in descending, and the old practice was returned to at the western abutment. In order to facilitate sinking, the diameter of the wells was, in all cases but one, reduced by an offset to 11 feet 3 inches at 20 feet above the curb. The material was excavated by dredgers worked by steam cranes, and consisted partly of clay and partly of sand, with a large number of stones. No difficulty was experienced in sinking except in one instance, in which the well canted in spite of all efforts to straighten it. Examination by a diver showed that it had fouled a broken

[1] Minutes of Proceedings Inst. C.E., vol. ciii. p. 135.

tie-rod of the neighbouring well. In nearly all cases the wells were sunk to within 4 feet of the rock without loading; in hard material the well was partly unwatered from time to time to aid the descent. When the rock had been reached by the dredgers, each well was heavily loaded with rails, divers being sent down to clear the material from under the curbs and dress the rock level; the wells were then filled with concrete under water by self-opening skips, the concrete being levelled by divers. The

Figs. 1.



Scale, 21 feet to 1 inch.

wells were connected by arches or corbelling, and the abutments built on them in coursed rubble, with cement mortar below the river bed and lime mortar above.

Piers.—Each pier consists of two cast-iron cylinders placed 18 feet apart, centre to centre, *Figs. 1.* They are 12 feet in diameter, for 42 feet above the cutting edge; a taper length of 7 feet 6 inches then reduces the diameter to 9 feet. The 9-foot cylinders are in lengths of 7 feet 6 inches. Extra lengths varying between 1 foot and

7 feet were supplied in order to make up the necessary height, the final adjustment being made by the cast-iron rings forming the caps. The curbs are of wrought-iron, 3 feet in depth; upon these is a 6-foot length in cast-iron on which is placed a 'bracket-ring,' 3 feet deep, having a horizontal annular shelf 2 feet 9 inches wide. Masonry was built on this shelf as the cylinder was sunk and carried up to 3 feet above the taper length. It was supposed that with this masonry lining, no top loading would be required. This was found to be so, in general, when sinking in sand, but when in clay and other hard material the result was different, and the disadvantage of thus cramping the working space was very marked. With open cylinders a grab holding two cubic yards could have been used, the weight of which would have been useful in enabling it to enter the soil. The masonry lining left a space in which a grab holding 15 cubic feet could work, and this only with careful handling. Further, a core of soil was removed, while the part under the bracket could not be reached by the dredger, and in clay did not fall in. Unwatering, top loading and dynamite in small charges alike proved useless. Divers refused to descend owing to the risk of being caught under the bracket in case of a sudden descent, such as had happened with one cylinder. An effective method was at length devised, by removing the buckets from a Priestman grab, and replacing them by large claws made from steel rails. These could be lowered clear of the bracket, then opened out, and dropped on to the shelf of clay to be removed. On closing the claws, the material was torn down into the centre and could be removed by the grab in the ordinary way. The sudden descent of one cylinder, referred to above, occurred when, after passing through a bed of clay, it struck soft soil below. The clay had been badly shaken by the use of dynamite and suddenly gave way. When relieved of its top load of rails it continued to sink and became buried 5 feet below the river bed and filled with sand.

The greatest error in position of any of the cylinders, when down to the rock, was $2\frac{3}{4}$ inches. In sand there was little difficulty in keeping true, but in clay, struts and chains had constantly to be used to prevent canting. The resistance to sinking, per square foot of surface embedded, was carefully measured, and was found to be as follows:—

In the upper sand,	between	2·08	and	2·20	cwts.
„ black clay,	„	3·50	„	5·60	„
„ silt below the clay,	„	2·72	„	4·28	„
„ the lower sand,	„	2·58	„	3·16	„

All the piers but one were carried down to the solid rock. As regards seven of them, the rock was reached by sinking as above described, and was dressed off by divers to a level bed under the cutting edge, thirty-two native divers being thus employed under a European foreman. With the other seven piers a bed of hard conglomerate was struck above the true rock, consisting of a mass of boulders, pebbles, and sand cemented by lime into what resembled natural masonry. In one case there was a thickness of 13 feet of this bed, and many of the boulders were between 6 feet and 9 feet long and 12 feet or 15 feet in circumference. Some had to be divided in order to pass them up the cylinder. The Author had originally intended to use the pneumatic process for penetrating this bed, and one pier was successfully sunk in this way. An epidemic of cholera then interrupted the work for two months of the working season, and on the resumption of work, the risk of floods precluded the use of heavy machinery in the river bed and led to the rest of the cylinders being sunk by divers working by hand. In the case of one pier the rock was so hard that the advance was only 6 inches in six weeks. Blasting was not considered safe, and in this case permission was obtained to bed the cylinder on the conglomerate. The total work of the divers on sinking these six piers amounted to 6,071 shifts of four hours each. The piers and wells were commenced on the 1st February, 1891, and the last cylinder was bedded on the 15th January, 1892.

The cylinders were filled with concrete under water up to 1 foot below the masonry lining, and were then pumped out and the space below the masonry packed with concrete. This last operation was troublesome, and in several instances could not be carried out in the dry as the water came in too rapidly. In those instances it was accomplished by divers. The cylinder was filled above the concrete with masonry, which, up to the river-bed level, was laid in Portland-cement mortar, and above, in lime mortar.

Superstructure.—The earlier spans were erected in the river-bed, and, after being riveted, were raised by hydraulic jacks, the piers being built up under them. This system had many advantages, but it had to be abandoned on account of the late arrival of the girders from England. It became necessary, therefore, to complete the piers without waiting for the girders; as, otherwise, another flood season would have been encountered, and an expensive staff would have been kept on the ground for a longer period. As it was, the delay with the girders retarded the completion of the bridge by five months. The later girders were erected on staging which, in the case of the spans near the shore, was built of spare

cylinders under each shipping joint of the lower boom, carrying a platform of sleepers, and, in the case of the channel spans, was built of trestles made up of old iron rails. The erection of each span occupied between three days and three and a half days, and the riveting, which was all done by hand, by native riveters, occupied between five days and seven days. There were 11,330 rivets in each span. The last girder was not received till June 1892, and on the 22nd of the same month the last rail was laid.

The bridge was tested by the Government inspector on the 1st July, with the following loads:—

——	One Span.				Per Lineal Foot.	
	Tons.	Cwts.	Tons.	Cwts.	Tons.	Cwts.
Dead load—						
Girders	146	12				
Rails and timber	12	16½				
			159	8½	1	3½
Live load—						
Two engines	132	2				
Two loaded wagons	44	11¾				
			176	13¾	1	6
Total load			336	2¼	2	9½

The deflection was uniform in the various spans, and amounted to about ½ inch. At a speed of 33 miles per hour, the maximum oscillation in the various spans varied between 0·16 and 0·37 inch, the average of the fifteen spans being 0·24 inch. The maximum permanent set in any span was 0·07 inch.

Cost.—The cost of the works was as follows:—

——	Total.	Per Lineal Foot of Bridge.	
	Rs.	Rs.	A.
Ironwork in piers and wells	2,54,409	121	0
" girders	3,26,533	155	8
Total outlay in England	5,80,942	276	8
Expenditure in India	4,51,026	214	8
Total cost of bridge	10,31,968	491	0

This includes no deduction for value of plant left in stock. The average cost of erecting girders, including staging and all charges after receiving the ironwork on the railway, was, Rs.1,780 2a. 2p. per span, or Rs.12 11a. 5p. per ton.

COST OF PIERS AND ABUTMENTS.

—	Total Expenditure.	Per Foot vertical.			Per 100 Cubic Feet of Contents.		
	Rs.	Rs.	A.	P.	Rs.	A.	P.
Sinking and bedding cylinders . . .	42,516	26	11	8	23	10	5
Divers	18,332		..			..	
Sinking in conglomerate	..	182	0	0		..	
Sinking by pneumatic system	..	218	0	0		..	
Total cost below river-bed, average for one pier	21,281	187	5	3		..	
Total cost above river-bed, average for one pier	4,342	194	14	8		..	
Sinking and bedding wells for abutments	..	14	13	6	13	2	0
Total cost of wells, including concrete, masonry, &c.	47,133	60	14	8	53	13	9

The Author had charge of the work throughout. It was entrusted to him by Mr. H. P. Carter, M. Inst. C.E., chief engineer of the Madras Railway.

The Paper is accompanied by five tracings, from one of which the *Figs.* in the text have been reproduced.

(*Paper No. 2833.*)

(*Abstract.*)

"The New Westminster Waterworks."

By Arthur Edmund Breton Hill, M. Inst. C.E.

New Westminster, the population of which is 8,000, is situated on the Fraser River, about 15 miles from its mouth, in British Columbia. It is served by a branch of the Canadian Pacific Railway, and is connected by an electric tramway with Vancouver. Its wharves are accessible to sea-going ships of heavy tonnage. The assessed value of property in the town is £1,550,000, and the municipal debt at the end of 1893 was about £186,600, of which £114,200 was invested in property yielding revenue.

In 1885 a scheme was prepared for the water-supply of Vancouver and New Westminster jointly, utilizing the Coquitlam Lake as a source of supply. This was to have been carried out as a private enterprise, but it was found impossible to raise the capital for it, and a rival company, holding a charter for Vancouver alone, constructed works of supply for that city at a cost of £50,000, thereby rendering it a more burdensome task to secure an efficient supply for New Westminster. The project became financially practicable only by the adoption of a riveted-plate pipe for the supply-main. In June 1889, the city acquired certain rights of the private company referred to, and decided to carry out the works. A special Board of Water Commissioners was established, to which the Author was appointed engineer, with instructions to prepare plans and specifications of works to meet both the existing and the prospective needs of the rapidly growing city.

The source of the supply is the Coquitlam Lake—a body of water of unexceptionable quality—about 7 miles long and between ½ mile and ¾ mile wide. The depth has not been measured, but is known to be considerable. The lake is surrounded by lofty mountains, which guard it from contamination, and is fed from snow-fields. The lowest level of the lake is 435·8 feet above high-water mark; it is subject to sudden rises of 9 or 10 feet, which, however, never impair the purity of the water. The nearest part of the lake is 71,581 feet from the reservoir at New Westminster, by the pipe-line. The supply is practically unlimited in quantity.

There are two in-flow pipes, so as to guard against the results of an accident happening to one of them. These pipes deliver the water into a screen-chamber, 3 feet in diameter and 18 feet high. This consists of eight castings, one of which is a heavy bed-plate, the rest being cylinders of 1-inch metal with spigot joints, and having suitable branches for connecting with the mains. The chamber contains vertical channel-iron guides for the screen-frames. The screens are of copper-wire, seven and fourteen wires to the inch, in wooden frames about 34 inches square. A small wooden building above the screen-chamber accommodates the care-taker or patrolman. The ground along the pipe-line was cleared to a width of 33 feet. For a considerable distance from the town the line follows a previously existing public road, and for the remainder of the distance a wagon road has been made and declared public. Along the old road the ground is of easy slope, but after leaving it the line is generally along steep hill-sides and across bluffs, with occasional stretches of swamp. There are numerous streams, some of which were underrun and others bridged. On side-hill ground a bench was cut for the roadway, and the pipe-trench cut on the inner side of it.

Except at one point, where the line was carried over a high bluff to reduce the length, it was kept below an imaginary line of uniform gradient, drawn from the source to a certain point in the city. At any future time, therefore, by laying a link round the bluff in question, the pipe-line could be made available for supplying, at its full capacity, an additional reservoir at any point that might be chosen in the city. In locating the pipe-line, it was purposely carried over a number of points of considerable elevation and almost precipitous slope, thus dividing the line into a series of sections, any one of which could be discharged for repairs without emptying the others, without the shock and strain arising from the use of stop-valves on the main. In streets the pipes were laid at a mean depth of 5 feet, on highways at about the same depth, in heavily-timbered forest land at 5 feet to 6 feet, in light timber at 4 feet to 5 feet, and on steep hill-sides at 7 feet to 10 feet. The gradients vary between 1 inch in 100 feet, and 87 feet in 100 feet. Angles of less than 4° were passed without special pipes. For larger angles cast-iron bends were used, and changes of gradient were made to coincide with changes of direction as far as possible, so as to economise in the number of bends used. The main is 14 inches in diameter throughout. The steel plate, of which the main was constructed, was manufactured under a specification requiring a tensile-strength of 65,000 lbs. per square

inch, and an elastic limit of 39,000 lbs. per square inch, with an extension of 20 per cent. on 10 inches. The plates and other material were supplied from Glasgow, and put together by the contractor at shops established for the purpose in New Westminster. Each plate was bent in rolls, and lap-riveted with two rows of rivets. The circular joints were also lap-riveted with single riveting, the plates being sheared to such a size as to make an exact fit between the smaller and larger pipes. Four of the larger and three of the smaller pipes were riveted together to form a 25-foot length. Each length was then tested by hydraulic pressure, cleaned and coated, and taken to the ground for laying. A thimble made from 5-inch strips, of the same thickness as the pipe, was riveted on the inside of one end of each length, projecting to fit into the end of the next length. A sleeve made from 5-inch × $\frac{3}{8}$-inch iron was passed over the joint and set up with lead in the usual way. The pipes were of four classes, the thickness varying according to the pressure to which the pipe might be exposed. The four thicknesses were B. W. G. Nos. 9, 10 and 11 and 12 (or 0·148, 0·134, 0·120 and 0·109 inch). The hydraulic tests with these plates corresponded to heads of 675, 625, 525 and 425 feet respectively. The corresponding rivets were $\frac{21}{64}$, $\frac{19}{64}$, $\frac{17}{64}$ and $\frac{15}{64}$ inch in diameter at a pitch of $1\frac{13}{64}$, $1\frac{6}{64}$, $\frac{63}{64}$ and $\frac{54}{64}$ inch respectively. Tight joints were obtained throughout the work. Trenching for the main was commenced about the 1st December, 1891, and laying about the 14th December. The water was turned into it on the 8th August, 1892.

The reservoir is on a ridge about a mile from the city, from which it is separated by a deep ravine. It is in good clay which formed excellent material for the banks. The reservoir was made by day-labour under the Author's direction, and the castings, valves, &c., were obtained from the Albion Ironworks, Victoria. The reservoir is rectangular, measuring 150 feet by 80 feet on the bottom, and with a depth of 15 feet the capacity is about 280,000 cubic feet. The water-level is 400 feet above the city datum (404 feet above high-water mark). The out-flow main from the reservoir is 22 inches in diameter, of steel plate, B. W. G. Nos. 9, 10 and 11, jointed and laid in the same way as the 14-inch main. A gate-chamber, 6 feet by 8 feet inside, was formed over the valve at the outflow, built of 4-inch cedar plank. It also contains a 6-inch open-topped pipe which serves instead of an air-valve. There is a 6-inch waste-pipe, from an overflow tank, delivering to a surface drain.

The 22-inch main has seven bends, five of which were of 90°,

and constructed for convenience in two lengths. There are four 4-inch air-valves, a 6-inch relief, and two 10-inch blow-off valves, supplied by the Glenfield Company, Kilmarnock. The 22-inch main connects with the two 14-inch steel-plate mains of the distribution system. On one of these is a relief-tank 20 feet in diameter and 6 feet deep, of brick laid in Portland-cement mortar, rendered with half an inch of neat cement. By means of this tank the pressure in the lower parts of the city is reduced, only the upper parts carrying the direct head of the reservoir; this was necessitated by the difference of level, amounting to 300 feet, between the upper and lower districts. In case of fire in the lower district, the full reservoir head can be made available, the two districts being cut off from each other by two 14-inch and four 6-inch valves. The service mains are chiefly of 6 inches diameter, of which size 89,936 feet have been laid. Seventy-three hydrants of the Galvin pattern have been established. The pipes were laid, as a rule, 15 feet from the street boundary, with a stop-valve 4 feet from each street intersection. Every summit and dead-end is provided with an air-valve; there are eleven 6-inch relief-valves on the system. Care was taken to have no avoidable summits between intersections. The house-connections are partly of lead and partly of ungalvanized wrought-iron pipe.

The trenches were 2·95 feet wide, on the average, at the top, and 3·82 feet deep. The cost to the city for trenching and laying was 11·4*d.* per foot run for 6-inch pipe, and 10·7*d.* for 4-inch pipe In the course of a dispute as to the allowance to a contractor for waste of lead in pipe-laying, a careful examination was made of the subject, and it was found that in the use of 30 tons of lead, almost exactly the quantity theoretically necessary for the joints had been used, so that the waste was inappreciable.

The condition of the works since opening has been satisfactory. During the winter of 1892–3 a trying ordeal of flood and frost was experienced without any interruption of the water-supply. When the temperature of the air was 12° F. below zero, that of the water in the reservoir was 37·5° F. The 14-inch supply-main, where exposed for about a thousand feet, was carefully watched and was always found to liquefy snow placed upon it. The Coquitlam Lake remained unfrozen for some distance above the outlet during the coldest winter on record, and the velocity of the water in its flow appears to be great enough to prevent the danger of the supply being interrupted by anchor ice.

The capacity of the supply-main at the mean head is about 110,000 cubic feet per day. The capacity of the 22-inch main

below the reservoir is sufficient to meet a fire draught of 200 cubic feet per minute, besides the ordinary domestic wants of a population of 22,000. In consequence of the efficiency of the supply, insurance rates have been reduced in the city.

The following Table gives an abstract of the cost of the works, up to December 1892:—

		$
Franchise		22,033·27
Land, buildings, and materials in stock		23,169·12
Works:	$	
Screen-chamber	1,148·61	
Patrol-house	620·99	
Supply-main (including clearing)	184,023·14	
Service-reservoir	17,921·29	
City mains	44,370·36	
Relief-tank	2,325·55	
Distribution system	110,614·16	
House service	5,490·18	
Extensions not included in original designs	3,340·57	
		369,854·85
Total		$415,057·24

Equivalent to about £85,140.

In this abstract the cost of interest, engineering, law expenses, &c., has been distributed *pro rata* over the various items. The cost of engineering and surveys was 4·24 per cent. of the total, and general charges 1·68 per cent.

The Paper is accompanied by ten drawings, five printed specifications, and a copy of regulations dated 1892.

(*Paper No. 2849.*)

"A New Formula for the Flow in Sewers and Water-Mains."

By William Santo-Crimp, M. Inst. C.E., and
Charles Ernest Bruges, Assoc. M. Inst. C.E.

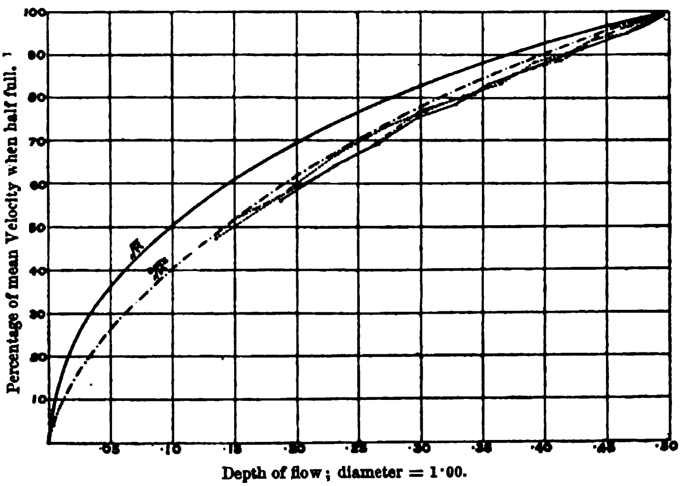
It is generally known that the fundamental formula relating to the flow of liquids in channels is that of Chezy, in which $v = c\sqrt{r\,s}$, where v is the mean velocity in feet per second, r is the hydraulic mean depth, s is the surface-inclination, and c is a coefficient. In this formula the frictional resistances are supposed to be proportional to $\sqrt{r}$, although recent research has shown that the resistances are not proportional to that power of r, but to other powers which depend upon the roughness of the wetted surface and upon other factors. This has been met in some later formulas by giving to the coefficient c a variable value, usually involving r, while the $\sqrt{r}$ is retained in the formula.

The Authors have endeavoured to construct a simple formula with only one coefficient for all sizes of channel, if of good brick-work or of cast-iron, which should be sufficiently accurate for every practical purpose and yet should give results closely approximating to those obtained by the use of the more elaborate formulas of Messrs. Darcy and Bazin, and of Messrs. Ganguillet and Kutter. This was found to be not difficult when once the square root of the hydraulic mean depth as a measure of frictional resistance was abandoned and some other power of r was substituted for it.

In determining the influence of the hydraulic mean depth on the mean velocity, it is necessary to have a complete series of experiments under precisely similar conditions as regard inclination and roughness of surface with varying values of r. This is furnished by several series of experiments by Messrs. Darcy and Bazin, giving the velocities corresponding with small variations of r in the same channel. In order to obtain a suitable power of r, the Authors plotted a series of these experiments on semi-circular channels having a gradient of 1 in 666·67, *Fig. 1.* They have also plotted in the same *Fig.* two curves, one involving

$\sqrt{r}$ and the other $\sqrt[3]{r^2}$, from which it is apparent that, as a measure of the frictional resistance, the latter function so nearly approaches the experimental results that it may be adopted as the base of a new formula. If it is objected that the experiments on the channel referred to were too few in number to warrant such a departure, the Authors can only refer to a series of diagrams prepared by them to show that plotting the formula $c\ \sqrt[3]{r^2}\sqrt{s}$, with a suitable constant coefficient c, a curve is produced which compares favourably with those plotted from the formulas of the best authorities.[1] Before deciding upon a value for c in the formula proposed, the Authors plotted a number of trial curves

Fig. 1.



EXPERIMENTS OF MESSRS. DARCY AND BAZIN ON SEMICIRCULAR CHANNELS AT VARIOUS DEPTHS OF FLOW REDUCED TO SHOW THE PERCENTAGE OF THE MEAN VELOCITY WHEN HALF-FULL, AND SHOWING COMPARISON WITH FORMULAS BASED ON $\sqrt{R}$ AND THOSE BASED ON $\sqrt[3]{R^2}$.

and finally adopted 124, because it was found to give a very close approximation to the curves of Darcy's and of Kutter's formulas for channels constructed of materials like those under consideration.

The Authors' formula, proposed for application to sewers and iron water-pipes, is

$$v = 124\ \sqrt[3]{r^2}\ \sqrt{s}.$$

A closer approximation might be obtained by the adoption of an-

[1] These diagrams may be consulted at the Institution.

other coefficient with a different power of s; but as for every-day use it is advantageous to possess a formula which can be employed without reference to tables, the Authors prefer the simple form given.

The application of the formula to flow in a brick channel is shown by some experiments conducted by Mr. W. Santo Crimp on one of the London sewers, in which the conditions admitted of careful observations being made.

In the King Scholars' Pond sewer, the old channel is for a considerable distance of great size, and had formerly a segmental invert with a gradient of about 1 in 2000. The dry-weather flow spread over a considerable breadth of the channel, and a foul deposit took place in it. To remedy this state of things, Mr. A. R. Binnie, the chief engineer to the London County Council, recommended the construction of a semi-circular channel, 3 feet wide, down the centre of the old invert, and Mr. Crimp directed the execution of the work. The bricks used were first quality High Brooms, extremely hard and presenting a very smooth face; they were set in carefully prepared cement mortar, and the joints were made with much care so as to ensure a perfectly smooth surface. The inclination of the new channel is 1 in 1200. This sewer is well adapted for experimental work, as a long portion of it is free from disturbing influences, and the water is therefore in a state of uniform flow for some time each day. In making the observations tabulated on the next page, a section of sewer 300 feet in length was selected, and an observer with a stop-watch was stationed at each end of the section. The times of passage of the floats (which were of paper) were accurately timed over this distance. As a rough check, the Authors poured a quantity of cream of lime into the sewer above the first point of observation, and noted the time occupied by the liquid thus coloured in travelling past the marks. The results approached the mean velocity as calculated from the surface velocity; but great accuracy is not attainable in consequence of the lag of the liquid in contact with the wetted perimeter of the channel.

If, in the Authors' formula, a coefficient of 143 were employed, instead of 124, the mean velocities (assuming them to be 0·83 of the centre surface velocities) would be obtained. But so great a velocity can hardly be expected with brickwork of a less highly finished character; whilst, on the other hand, as Darcy classes brickwork with ashlar, a higher value than 117 may be safely employed, that being the value for that material based on Darcy's somewhat meagre observations in regard to it.

The following results were obtained after the channel was brought into use:—

KING SCHOLARS' POND SEWER, 1893. SEMI-CIRCULAR BRICK CHANNEL, 3 FEET WIDE.

Experiment No.	Depth of Sewage.	Hydraulic Mean Depth in Feet.	Observed Central Surface Velocity in Feet per Second.	Mean Velocity. Assuming it to be 0·83 of Central Surface Velocity.	Mean Velocity. By Darcy's Formula.	Mean Velocity. By Authors' Formula, $124\sqrt[3]{r^2}\sqrt{s}$.
	Ft. Ins.					
1	1 0¼	0·563	3·450	2·860	2·33	2·443
2	1 0⅛	0·560	3·448	2·858	2·31	2·434
3	1 0⅛	0·560	3·450	2·860	2·31	2·434
4	1 0	0·558	3·448	2·858	2·30	2·429
5	1 0	0·558	3·333	2·766	2·30	2·429
6	0 11¾	0·547	3·300	2·730	2·27	2·397

With the coefficient selected, 124, the formula may be seen, on reference to the diagrams previously alluded to, to give a close approximation to Kutter's formula when n lies between about 0·012 and 0·013.

The values of n in Kutter's formula for two cases experimented upon by the Authors are

(1) King Scholars' Pond sewer (new brickwork, very smooth) . . . . $n = 0·0095$.

(2) Northern outfall sewer (smooth brickwork, bottom five courses slightly eroded after being in use 28 years) . . . . . . $n = 0·0122$.

In conclusion, the Authors feel assured that, so far as the materials mentioned are concerned, the results by the proposed formula will give trustworthy results, erring, if at all, on the side of safety; and that, whilst possessing the advantage of needing only one coefficient for all sizes of channel, it is preferable for every-day use to expressions of a more complex character.

The Paper is accompanied by nine diagrams, one of which is reproduced in the *Fig.* in the text.

(*Paper No. 2901.*)

(*Abstract.*)

"Light Railways for the Transport of Sugar-cane in Australasia."

By Charles Edward Forster, B.A., Assoc. M. Inst. C.E.

The Colonial Sugar Refining Company of Sydney has been in existence for more than fifty years, and now has refineries in Sydney, Melbourne, Adelaide, Auckland and Brisbane, which are supplied with raw sugar from nine mills owned by the company in New South Wales, Queensland and Fiji, supplemented by purchases from various producers. The quantity of cane transported from the fields to the nine mills mentioned is between 600,000 and 700,000 tons during a crushing season which lasts between six and seven months. At the mills in New South Wales water-carriage is available; in Fiji railways are principally used for the transport, and in Queensland exclusively so. The average quantity carried by rail in one season exceeds 400,000 tons. The plant employed for the purpose is constantly being increased, and at the present time comprises, approximately, 120 miles of permanent line, 90 miles of portable line, 25 locomotives, 4,000 cane-wagons and 200 wagons for sugar and general purposes.

Earthwork and Gradients.—The plantations are generally in fairly level country, and easy gradients can be obtained without much earthwork. Occasionally, cuttings and banks as much as 15 feet in depth have had to be made. In general, an embankment of 1 foot to 2 feet in height is made with earth from side-drains. The formation width is 10 feet, the side slopes being about 1½ to 1 in banks, and between ½ to 1 and 1 to 1 in cuttings. The cost of earthwork averages £60 to £80 per mile. The lines are arranged so as to have a gradient of 1 in 200, if possible, towards the mill; *i.e.*, with the load. It is found that steeper gradients than 1 in 100 should be avoided, because, the wagons being unprovided with brakes, there is some danger of derailment occurring at the bottom of any steep gradient from the bumping together of the wagons.

Bridges and Culverts.—These are usually of timber and of the simplest character. The bridges can be built for about £1 per foot run. When larger bridges are required, a composite truss with iron or steel tension members is used.

Permanent Way.—The gauge is 2 feet. The permanent lines have flat-footed rails, usually weighing 24 lbs. per yard, either fastened to hardwood sleepers by dog-spikes measuring 4 inches by ½ inch, or else bolted to steel sleepers. The steel sleepers are 4 feet long by 6 inches wide, weigh 28 lbs. each, and are spaced 2 feet apart. The hardwood sleepers are 4 feet 6 inches by 8 inches by 4 inches, and are spaced 2 feet 6 inches apart. In the coast districts a wooden sleeper costs 7*d.* delivered, against 2*s.* 6*d.* for a steel sleeper; but the life of the former is short, frequently not exceeding four years. What the life of the steel sleeper may be is not yet known, but the Author recently examined some that had been down for five-and-a-half years and found very little corrosion. It seems likely that they will have three or four times the life of timber sleepers, and they possess the advantage of not necessitating disturbance of the road so often for repairs and renewals. Owing to the great difference of cost, however, they have not been extensively used. The sleepers are generally packed with earth, but the heavy rainfall affects such a permanent way somewhat severely; and where coarse sand or gravel could be procured at a moderate cost, say, 2*s.* to 3*s.* per cubic yard, it has in several cases been used. It is believed that the saving in maintenance will eventually repay this additional outlay. Curves on the main lines have a minimum radius of 90 feet, but on sidings and in the mill-yards a radius of 60 feet is used, which is about the smallest which the locomotives can pass over. Lines such as those described, where the earthwork is light and no ballast is used, can be constructed for about £700 per mile, exclusive of rolling-stock and cost of land.

Portable lines.—On these lines the motive power is furnished by horses. The rails, weighing 14 lbs. to a yard, are in sections of 16 feet 6 inches long, with six steel sleepers to each section. Each section when made up weighs about 212 lbs. and can be easily handled by two men. These portable lines form the means of communication between the cane-fields and the permanent lines. The junction is usually effected by a turn-out of the ordinary type, but where a temporary connection only is required, an inclined plane or riding-points is used. This serves very well, notwithstanding that it has to be lifted from the rails whenever a train passes on the main line. A turn-out of this kind can be equally well applied

either to the portable or to the permanent line. A portable line, when laid across a cane-field, is used to clear off all the cane within a distance of half a chain to one chain. It is then removed to a parallel position at a distance of one or two chains, and so on until the whole crop has been harvested.

Rolling-stock.—The locomotives are of several types, but most of them are carried on two pairs of coupled wheels, and weigh in working order between 9 and 10 tons. The following particulars of two such engines may be of interest. The first column refers to an engine made by the Decauville Co., and the second column to an engine made by Messrs. John Fowler and Co. Both have outside cylinders and plate frames.

PARTICULARS OF LOCOMOTIVES.

Diameter of cylinder	$8\frac{5}{16}$ inches	7 inches
Stroke	$12\frac{5}{8}$ "	12 "
Area of grate	5·42 sq. ft.	4·5 sq. ft.
Heating-surface	129 "	146 "
Diameter of driving-wheels	$21\frac{1}{2}$ inches	$22\frac{1}{2}$ inches
Wheel-base	4 feet	5 feet
Weight in working order	9 tons	10 tons

Either engine will haul a gross load of 90 tons up a gradient of 1 in 200 under favourable conditions, but the ordinary working load would be 60 to 70 tons. Both are tank-engines with a capacity of 300 to 400 gallons of water. The average speed is about 8 miles per hour, and 10 miles per hour is rarely exceeded.

The cane-wagons are of wrought-iron, with cast-iron wheels 1 foot in diameter and 3 feet 3 inches apart. There are no sides, the canes being laid transversely and often overhanging 2 feet on each side. The floor of the wagon is 5 feet long and 4 feet wide, and the ends are protected by a framing of light iron bars. Each wagon carries about 1 ton. The wagons are unloaded at the mill by hand, and the cane is conveyed by an endless band to the crushers.

In applying railways of this kind to agricultural purposes, it must be remembered that there are few, if any, crops that yield so large a weight as does sugar-cane—frequently amounting to 40 tons and sometimes to 70 tons to an acre.

The Author is indebted to the general manager of the Company for permission to make use of the information given in this Paper

(*Paper No. 2862.*)

"Tarred Foot-paths in Rural Districts."

By Edgar Purnell Hooley, Assoc. M. Inst. C.E.

An important objection to the use of tarred foot-paths has hitherto been the effect of the sun's heat upon them, but with the mixture hereafter described that difficulty is largely obviated. The chief advantages claimed for such foot-paths are,—cleanly appearance, freedom from slipperiness, cheapness, simplicity of manufacture, avoidance of the inconveniences attending the employment of patent processes, and free use of the paths during construction.

The tarred foot-paths in Nottinghamshire are made thus:—Slag or furnace refuse from ironworks, obtained in the neighbourhood, is the material principally used as the aggregate, but gravel, screened, washed and dried, would do equally well for "bottoming." It is essential all material should be perfectly dry, and should be warm when mixed with the tar. The processes of drying and warming in country districts, where no drying-floors are available, must be carried out in fair weather; the material being heated in convenient places out of doors, by fires lighted under heaps of about 10 tons of material at one time. The method of drying adopted by the Author is to lay four sections of ordinary 4-inch glazed pipes in the form of a cross leading to a central upright section of pipes which forms a chimney. Faggots and breeze are laid around the pipes, and when well alight, the material is gradually added in a cone-shaped heap and is allowed to dry slowly. When the material is dry, and warm enough to allow the hand to be held on the surface without discomfort, it should at once be mixed with the tar-mixture, which has been boiling thoroughly whilst the heap has been drying. After having been mixed and again heaped up, it should be allowed to stand for at least a week, though it will be better if it is left for three weeks or a month before being used.

The tar-boiler is capable of containing 100 gallons, constructed with an enclosed furnace underneath it, and for convenience of moving is placed on three wheels, each wheel being 18 inches in

diameter. The mixture to be boiled consists of:—tar 40 gallons, pitch 28 lbs., Portland cement 20 lbs., resin 6 lbs.

The boiler must be well cleaned occasionally, and always be completely emptied after each operation. The tar is the first ingredient placed in the boiler, and is allowed to simmer gently for an hour before the other substances are gradually added. The whole is then thoroughly stirred in the boiler, and afterwards allowed to boil gently until it attains an equal consistency throughout. Great care must be exercised to prevent the boiling tar-mixture from igniting, but after a little experience, any intelligent workman will become a good judge of the heat required. Before applying the mixture to the stone, it is allowed to cool down slightly, until, when mixed with the warmed stone, it does not give off vapour but mixes easily. When the mixture is in this condition, a bay, similar to that made for mixing mortar, is formed of the heated slag or stone, and the tar-mixture is poured into the centre of it, the stone being carefully turned over until the whole forms a sticky mass. It is again turned three times whilst in this warm condition, being finally heaped up. It will then, if properly mixed, be found to be in a state known to the workmen as "alive," having that appearance if moved with a shovel. After the material has been thus mixed, the bottom of the foot-path is properly shaped, and curb-stones are laid as required. If the ground is wet, cross drains are formed to dry the bottom before the tarred material is laid on. The Author has found a good bottom secured by using a bed of ashes, pit-refuse or clinkers, up to within 4 inches of the curb level, this bed being well and evenly rolled. The coarse tarred material is next applied, and is rolled to form a bottom layer 2 inches thick. A water-ballast roller with round edges is the best implement for this purpose. If the tarred material should stick to the face of the roller, a water-can may be attached to it, and a slight trickle of water be allowed to play continually on the face; or the latter may be dressed three times a day with common oil, which will generally prevent any sticking. When the bottom layer has been well rolled, further layers of finer material are applied, $\frac{3}{4}$ inch thick at a time, until $1\frac{1}{2}$ inch in thickness is obtained after rolling. Fine topping is then applied in layers, and rolled until it is 1 inch in thickness, any outside portion that the roller cannot reach being rammed. The face of the path is now quite smooth. It is almost impossible to roll a tar-path too much or too carefully. It is rolled so as to allow of a fall to the edge of the path or water-

course, of 1 in 48. The path is left "proud" about $\frac{1}{2}$ inch over the curb. After the final rolling, the face is carefully washed over with the boiling tar-mixture, and whilst moist it is dusted or blinded with very fine dry gritty granite or slag dust, mixed with cement in the ratio of 1 part of cement to 7 parts of dust. The path is now finished, and will be found to have a perfect face, neither slippery in winter nor spongy in summer, but firm and comfortable for pedestrians. In Nottinghamshire, during 1894, such foot-paths cost 1*s.* 2*d.* per square yard.

The repairs necessary are slight. Where the traffic is heavy, the face should be washed over every second year with a dressing of the tar-mixture and blinded with cement and dust. Should any signs of wear appear, they should be cut out in the top layer and patches should be inserted, the whole being washed with boiling tar and blinded. Sometimes it may be necessary to renew the top dressing, but the traffic must be exceptionally heavy for this to be required more frequently than once in six years.

(*Paper No. 2871.*)

(*Abridged.*)

"Foot-ways."

By CHARLES HAMLET COOPER, Assoc. M. Inst. C.E.

THE repair of foot-ways and bridle-paths is often essential to the maintenance of the public right of way, as well as to the convenience of the inhabitants in any given district. In towns, the authorities are compelled to attend to the foot-ways, especially in those residential districts and pleasure resorts to the prosperity of which the convenience of pedestrians is essential. In many rural and semi-rural districts, the authorities consider that economy is effected by constructing narrow footpaths, which frequently oblige pedestrians to use the carriage-way. Whenever it becomes necessary to pave such paths, the cost is considerably increased, as they have to be widened, new gulleys have sometimes to be constructed, and the material formerly laid on the portion of the carriage-way required to be taken in is practically wasted. In the district of Wimbledon, the width allowed for the foot-way on each side of the carriage-way is one-fifth of that of the entire road.

In laying out intended streets, the works which have to be constructed before building operations are commenced deserve much consideration. Some engineers think the paths should be formed in the first instance with a foundation covered by a layer of gravel, so that the builder, when laying drains and gas- and water-connections, need not disturb the finished path. It must, however, be remembered that in such cases the occupiers of the houses are subjected to the inconvenience occasioned by bad foot- and carriage-ways until the road is taken over by the authorities. This seldom occurs before the road is half built on, so that such occupiers may be inconvenienced for many years, during which time they reap no benefit, in respect of the particular street in which they live, from the highway rates. If, before the commencement of building operations, roads were made up in a permanent manner with curbed and paved paths, and were taken over by the authorities as "highways repairable by the inhabitants at large,"

the occupiers of houses built in such roads would be spared much inconvenience, and the builders would be greatly benefited. Local authorities have no power, except where special Acts may exist, over the materials used in the construction of new roads and paths. It is not until a road has become a street that the local authority's power to compel the owners to construct it, under Section 150 of the Public Health Act of 1875, can be enforced.

Channels and Curbs.—Although channels do not form part of footpaths, they are important adjuncts to them. A channel protects the path against disturbance from rollers and the wheels of carts using the carriage-way, and it affords drainage and prevents the path from being saturated by the water flowing off the carriage-way. Much may be said in favour of a flat curb, which affords a substitute for paving where gravel paths are allowed to fall into dis-repair. A flat curb is more liable to be displaced than an edge curb, but this liability can in a great measure be removed by placing it on a bed of concrete. The Author prefers an 8-inch by 12-inch edge curb for main roads, and a 6-inch by 12-inch edge curb for ordinary roads. Aberdeen granite forms the best wearing curb, but, owing to the reduced price at which Norway granite is delivered, little of the former is now used in and around London. Newry and Cornish granites are used, but neither of them are well dressed; and so far as the Author has seen both are coarse grained. Guernsey granite is used in some districts, but, as it is very hard, it becomes slippery, and further, it can only be procured in short lengths. The Author has had experience of curbs made from Purbeck, Kenton and Pennant limestones, but, with the exception of the latter kind, he has not found limestones to be suitable for curbs.

Although on dry gravel or sand, foundations for paths may as a rule be omitted, on other ground the foundation forms the principal part of their construction. The Author prefers a layer of furnace-ashes, or, in the case of concrete *in situ*, furnace clinker, to any other material that can be easily procured in the neighbourhood of London. A layer of either material, 4 inches thick, affords ample drainage, and prevents frost from penetrating to the soil beneath and disturbing the path. The foundation should be well rolled and exposed to traffic as long as possible before the paving is laid. Every care must be taken to cut off all springs and water that would be liable to soak under the path, and for this purpose it is sometimes necessary to lay a rubble drain at the back of the path. For paths which it is not intended to pave, a layer of fine binding gravel about 4 inches in thickness is generally placed

on the foundation described, and is well watered and rolled. Although such a path may answer in certain dry situations where there is not much traffic, it becomes impossible to maintain it in a satisfactory condition in low-lying districts, or where there is considerable traffic. Gravel never forms a pleasant path for pedestrians, and is expensive to maintain. The use of dressed York stone has been discontinued at Wimbledon for many years on account of its cost and the uncertainty with which it wears. Such stone laid sixteen years ago was removed last year, the greater part of the flags being worn through; whereas concrete slabs laid about ten years ago have not worn $\frac{1}{8}$ inch, although subject to quite as much traffic as the York stone. Apart from the effect of traffic, the weather disintegrates York stone, causing it to laminate.

Concrete Paving.—The materials used to form the wearing part of most concrete pavings, whether the concrete is formed into slabs or laid *in situ*, are practically the same, viz., granite broken to the size of pea gravel, *i.e.*, $\frac{3}{16}$ inch in diameter; Portland cement ground fine and well cooled; and frequently a solution of silicate of soda. Much depends on the way in which slabs are laid. Good foundations should be provided, with a top layer of fine material, either sand or ashes, on which a layer of poor hydraulic-lime mortar is spread as a bed for the slabs. It is important that no part of the slabs be left unsupported. In no case should slabs be allowed to break joint more than 8 inches; and it is well to use two sizes of closers, so that the joints on each side of any slab may not be opposite one another. When slabs lap so as to break joint on each side of the centres of the intervening slabs, it is a common practice to have several slabs split across the centre for a considerable distance. The slabs when laid should be run in with grout made from mortar, similar to that used for the bedding. Concrete paving *in situ* was first laid in Wimbledon in 1884, on the west side of Wimbledon Hill. In 1892, this paving was removed and was relaid in Denmark Road and South Road, few of the panels being damaged. This is the only case within the Author's knowledge of paving *in situ* being relaid. In relaying such paving, a space of about 3 inches should be left between the panels, to be subsequently filled in with concrete. The concrete was laid on a foundation of 4 inches of clinker, or brick rubbish, sufficient to give 2 inches in thickness when finished without the addition of any surface-coat, the fine material being brought to the surface by tapping with trowels. Screeds formed of wood strips 2 inches by $\frac{1}{4}$ inch were laid on the foundation between 6 feet and 4 feet apart across the path. Into each

alternate bay formed by the screeds, granite concrete was well worked so as to remove all cavities, and the face was trowelled off smooth. After the panels thus formed had well set, the intermediate bays were filled in and worked similarly, the wood strips being left in so as to prevent the panels adhering to one another.

In 1894 the Author laid 13,700 square yards of granite-concrete paving 2 inches thick. This paving was laid on a foundation consisting of the gravel which had formed the old path; or where such gravel was not 4 inches thick, the deficiency was made good with furnace-clinker. The concrete consisted of Guernsey granite chippings and cement; it was deposited in two layers, the first being $1\frac{1}{4}$ inch thick, composed of chippings that passed through a $\frac{3}{8}$-inch mesh and were retained on a $\frac{3}{16}$-inch mesh, mixed with cement, gauged 4 parts of chippings to 1 of cement. For the top layer, $\frac{3}{4}$ inch thick, the chippings were passed through a $\frac{3}{16}$-inch mesh, and cement was added in the ratio of 1 part of cement to 2 parts of chippings. This layer was placed on the bottom layer within half-an-hour after the bottom one was laid. Each layer of concrete was well worked after being placed in position, the surface of the top layer being trowelled off smooth. The panels were kept apart by flat iron bars which were withdrawn after the concrete had been laid; and strips of wood, 2 inches deep and $\frac{1}{8}$ inch thick, were then inserted before the face was trowelled off.

In laying carriage-crossings, the Author has for some years dispensed with the usual drop, the crossing being laid at the same level as the path, except where it slopes to the channel, the curbs on both sides being stopped off with a quadrant. Such crossings are laid in concrete 4 inches thick, and the surface, after being trowelled off, is grooved in a herring-bone pattern, the grooves being about $3\frac{1}{2}$ inches apart, so as to afford foothold for horses.

Valve-boxes are covered with concrete slabs moulded in boxes, in which are inserted two rings buried beneath the surface, with hollows formed so that hooks can be passed through the parts of the rings which are exposed.

In all concrete paving the materials used should be perfectly clean, of fairly uniform size, and the cement should be finely ground and cool. Work *in situ* cannot be satisfactorily executed in frosty weather, and cloths must be used to protect fresh panels against the rain and sun. During dry or hot weather it is important that the panels be kept constantly wet and free from traffic for at least a week after they are laid.

Brick-Paving.—The appearance of brick-paving for foot-ways is

not in its favour, nor does it afford a pleasant surface to walk upon. At the same time it has many advantages, and is well suited for streets in manufacturing districts, where well-burnt bricks can be obtained. It can be removed and relaid at a small cost without interfering with the appearance of the path, and this is greatly in its favour, especially where a path is liable to be disturbed by house-connections. The brick pavements laid in Wimbledon rest on a foundation of furnace-ashes, with a layer of fine sand, about $\frac{3}{4}$ inch thick, to form the bedding on which the bricks are laid. The bricks are placed as close together as possible, and the joints are run in with sand and water. It is important that the bricks used for footways should not possess so vitrified a surface as to be slippery, and that they should be burnt throughout. The Author prefers large bricks to small, not only on the score of economy, but also because they form a pleasanter surface to walk over. He has tried brick crossings with bricks $4\frac{1}{2}$ inches deep, but, although such crossings answer well for light traffic, they cannot withstand the wheels of heavily-laden vehicles.

Tar-Paving.—The manufacture and laying of tar-paving deserves much more attention than is generally bestowed upon it. In no case should gas-tar be used until it has been stored for about six months, so that the volatile oils and whatever water may have been secreted in the tar has had time to escape. The tar should be drawn from the bottom of a covered tank at least 10 feet deep. If it cannot be obtained under such conditions, refined tar (not pitch or heavy oils) should be used. The Author recently discovered coke breeze to the extent of 12 per cent. in a consignment of tarred topping that was intended to be used in the Wimbledon district. It is almost needless to say that such soft material as coke-breeze must considerably reduce the life of the paving, especially when added in the quantity mentioned. Coke-breeze may be detected in tarred topping by removing the tar by repeated boiling in water to which a large quantity of soda or potash has been added. In this way the stone used in the manufacture is cleansed, and its nature can be easily determined. This test affords in addition a means of determining whether or not the stone has been raised to a sufficient heat to thoroughly absorb the tar. If such heat has been insufficient, the tar can be easily removed from the stone, which it leaves perfectly clean; whereas if the stone has been raised to a sufficient heat, the tar will have been so thoroughly absorbed that it is difficult to remove, and even after repeated washings the stone presents a dull dirty appearance.

In the best method known to the Author for the manufacture of tar-paving, the stone is heated on a hearth on which it can be raised to such a temperature as to absorb as much tar as possible without ignition. With this method there is no liability of coke, ashes, or other foreign substances to become mixed with the stone. Hot tar is added to the heated stone, which is then turned over with hot shovels until all parts are well coated. Many manufacturers add a small quantity of pitch (about 1 per cent.) to the cauldron in which the tar is boiled. Tar-paving thus made should be stored for at least three months before being used. It is frequently freshened with a little refined tar before leaving the works. The size of the stones used should be fairly uniform, those for the bottom, termed "bottoming," should not exceed 1 inch in diameter, and all the stone used should be retained on a $\frac{5}{8}$-inch mesh sieve. In the case of the material for the top layer (the "topping"), the material should pass through a sieve of $\frac{3}{8}$-inch mesh and be retained on a sieve of $\frac{1}{8}$-inch mesh. Derbyshire spar and Kentish rag produces the best tar-paving that the Author has used, but he is of opinion that it would be advantageous to use a harder substance for the topping.

In laying tar-paved foot-ways the Author forms the foundation to the slope of the finished path. This, after being well-rolled, receives sufficient "bottoming" to form a layer 2 inches thick after being rolled. A light roller is used, weighing, say, 5 cwt. on a width of 2 feet 6 inches. It may afterwards be finished with a slightly heavier roller. The "bottoming" may with advantage be subjected to traffic for a week or so before receiving the finished coat of "topping," which should be carefully spread in a layer of sufficient thickness to solidify to 1 inch after being rolled. The topping is first rolled with a light roller, and is finished with a double water-ballasted roller 2 feet 3 inches wide over all, weighing 12 cwt. A little white spar is generally thrown on the top and rolled in for the sake of appearance, the surface being afterwards sanded to prevent the tar from adhering to the feet of pedestrians. For carriage-crossings the "bottoming" is laid 3 inches thick covered with an inch of topping as previously described. The process of repairing tar-paved paths by covering them with a coat of topping is a risky operation, for if wet weather sets in the rain soaks through the new topping, which, as the old path is impervious, becomes saturated with water and works into a soft butter-like mass. Only seasoned topping should be used for coating old paths. Tarring and sanding, or, as it is termed, "dressing," the surface of tar-paths should be carried out in dry

weather during the first summer after the tar-paving is laid, and afterwards triennially. The seasoned or refined tar used for this purpose should be heated in a cauldron with a little pitch. After the surface of the path has been swept clean, hot tar is well rubbed in, and a layer about $\frac{3}{16}$ inch thick of dry sharp sand is spread on the tar so as to keep it from adhering to the feet of pedestrians. As this sand is forced into the tar by the traffic, it forms a thin coating which prolongs the life of the path considerably.

Asphalt Paving.—Asphalt forms a good paving for level foot-ways. Unfortunately, on account of what is technically termed "creeping," it cannot be laid on paths which have any considerable inclination, as cracks are apt to occur in it which gradually increase in width. Such paths are laid on a foundation of about 3 inches of concrete, the thickness of asphalt used being about $\frac{3}{4}$ inch. This kind of paving cannot, like tar-paving, be repaired. Only a small amount of asphalt has been laid in the Wimbledon district, but its life has not been found to compare favourably with that of concrete-slab paving.

(*Paper No. 2894.*)

(*Abridged.*)

"The Maintenance of Macadamised Roads."

By Thomas Aitken, Assoc. M. Inst. C.E.

The object of this Paper is to give a description of the methods adopted, and the results obtained by the use of machinery, in the repair and maintenance of macadamised highways in the Cupar district of the county of Fife.

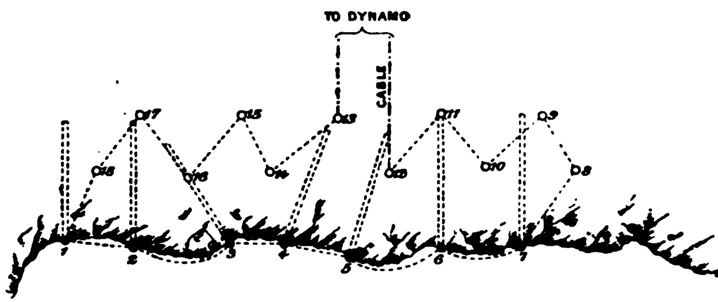
The system formerly in general use of laying small patches of metal on the worn portions of highways in the autumn of each year, for subsequent consolidation by the traffic, presents many disadvantages. The quarrying of the material, its reduction to metal by hand and storage in depôts for the following winter's use, involved slow production, second handling, and a resulting metal containing a considerable quantity of useless material. The short day and inclement weather inseparable from the season of the year in which, under the old system, the work had to be carried out, also occasioned a heavy annual expenditure on labour. Metal spread on the road direct from the quarries, or even when prepared in roadside depôts, contains a large amount of debris, which is, under the traffic, soon pulverised, necessarily producing much soft material in the coating of the road. In wet weather this creates a considerable quantity of mud, and in consequence scraping and cleaning are continually required, adding to the cost of maintenance. Although metal properly broken by hand possesses many points in its favour, the quality now generally obtained cannot be considered in any way superior to that produced by good stone-breaking machines. One disadvantage is that the former contains much small material, and after application to the road-surface the traffic soon converts the patched portion into a series of hollows, resulting in what is known as a bumpy surface. A steam-roller can consolidate between 60 tons and 80 tons of metal in one day; and it is evident that an army of stone-breakers, which it would be impossible to find in such a district as that under consideration,

would be required to carry on the work of rolling uninterruptedly at an equal rate. The cleaning of the road-surface by hand-machines is a slow process, and in many cases the changeable nature of the weather precludes extensive or continuous work.

The machinery employed in the maintenance of the roads in the Cupar district comprises:—Rock-drill with cylinder 3¼ inches in diameter; hand-dynamo blasting-machine; stone-breaker, 16-inch by 9-inch portable automatic breaking, screening, and loading machine; traction-engine or road-locomotive for driving the stone-breaker; weighing-machine; 15-ton steam road-roller; road-locomotive wagons; horse scraping- and sweeping-machines; and "steam-scarifier," for lifting or "chequering" roads.

Quarrying.—The stripping, which first demands attention, may be carried on during frosty weather when men can be spared from

Fig. 1.



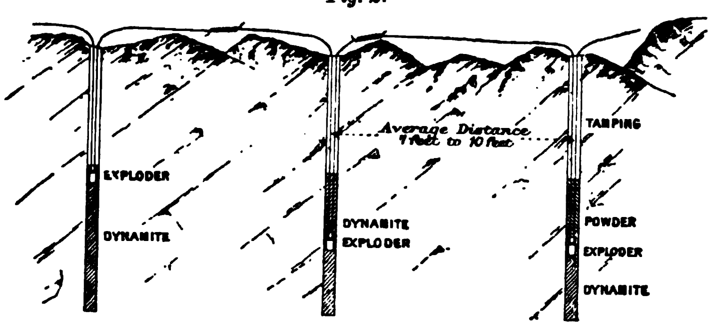
Scale, 1 inch = 20 feet.

the ordinary road-work, or it may be, and generally is, done immediately before the drilling-operations are commenced. It is desirable that the rock-face should be thoroughly cleared of earth, so that the drill-operator may be able to set out to the best advantage the positions of the holes that are to be drilled. Different sizes of drills are employed according to the class of work undertaken; drilling between 4 feet and 40 feet in depth being accomplished with "bits" between 2½ inches and 4 inches in diameter.

The primitive system of firing the shot-holes singly by black powder and fuse, has been discarded in favour of high-grade explosives connected in series and fired simultaneously by electricity. At times, however, a small quantity of black powder in conjunction with the higher grade of explosives is desirable

and even necessary. Dynamite containing 75 per cent. of nitro-glycerine suits this class of work well, its great disruptive power shattering the rock and saving subsequent manipulation. The large hole made by a rock-drill permits the concentration of a considerable quantity of explosive in the lower part of the shot-hole. In using an explosive of the grade mentioned, experience has shown that 1 lb. of dynamite will throw down between 10 and 12 tons of the rock found in this district. The method usually followed is to calculate roughly the solid contents of the rock to be blasted, in relation to the depth and position of the holes, allowing 1 ton to every 13 cubic feet of rock in the solid, *Fig. 1.* (The face of rock here illustrated is 20 feet high.) Due allowance, however, must be made for fissures running through the rock, which, in some cases, aid the work. When the face is badly

Fig. 2.



locked, it is sometimes advisable to fire one or two shots singly in order to relieve as much as possible the general body of the rock. The object is to use sufficient explosive to shatter the rock and thereby to save sledging it to a suitable size for the stone-breaker. The hand-dynamo for firing the charge should be able to generate a strong current of electricity, so that between twenty and twenty-five holes may be fired at once with certainty. After charging the holes, the electric fuse is inserted in the dynamite at the top or in the middle of the charge, the remainder of the hole being tamped with suitable material, care being taken not to disturb the insulation of the wires leading from the charge, *Fig. 2.* The intermediate shot-hole wires are connected in series, and the last wires of the end holes are joined on to the cables, which in turn are connected with the terminals of the blasting-machine.

The electric exploders now manufactured are very reliable if kept free from damp, and miss-fires are of rare occurrence. Blast-testing machines are also made, so that the exploders may be tested previous to inserting them in the explosive. In the event of a miss-fire, it is advisable to drill another hole 2 feet or 3 feet distant, and deep enough to reach the level of the top of the explosive in the miss-fired hole. The relief charge being fired, and the loose rock cleared away, a new exploder is inserted in the dynamite of the miss-fired hole, after which it is connected with the blasting-machine and fired.

Stone-Breaking.—It is unnecessary to describe the features and action of the stone-breaking machines. The quantity of rock broken by one machine, taken over a number of years, has amounted to 75 tons per day of 9 hours. The chips and gravel, however, amount to 3½ cwt. per ton of rock, so that the actual quantity of metal is 64 tons. The largest amount broken in one day was 77 tons of metal, *i.e.*, 90½ tons of rock. Every cart-load of metal is weighed before leaving the quarry, and the ratio of chips, &c., to metal is ascertained repeatedly during each week. The empty carts are passed over the weigh-bridge occasionally to verify the weight of each, but during wet weather this is done daily. The chips from the breaker are applied to foot-paths and for finishing off rolled roads, the gravel being used for patching hilly portions of the highways. In certain quarries large quantities of chips are sold when not required for road work, the quantity supplied to the different departments being credited to the breaking-account. The actual cost of breaking by machine is 8·61*d.* per ton of rock broken, *i.e.*, 9·86*d.* per ton of metal, which, with allowance for lost time, may be fairly stated to cost 10¼*d.* per ton. A prominent feature in machine-broken metal is that a regular size may be obtained by proper screening. It will, therefore, when consolidated by the steam-roller, present a surface of as nearly as possible equal strength. This cannot be attained with ordinary hand-broken metal.

The limited area of many of the quarries and the steepness of their approaches prohibit haulage by steam-power. This condition of matters is improving, and, when further developed, economy in that department may be looked for. The haulage is at present performed by horses. Tip-carts are only used in conveying and depositing the metal. The cost of haulage ranges from 7½*d.* to 7¾*d.* per ton per mile. The number of carts necessary to carry on operations uninterruptedly, with an allowance of six minutes

to eight minutes to load at the stone-breaker, is generally five or six to every mile of travel between the quarry and the work. The average load of the carts is 25 cwt. of metal.

Rolling.—Rolling and breaking operations are commenced early in the spring, and are carried on till late in the autumn, generally extending over seven or eight months. The steam-roller employed weighs 15 tons. The rear or driving-wheels are 6 feet in diameter and 18 inches broad, the front wheels being 3 feet 9 inches in diameter, with a combined width of 4 feet 10 inches. The width of road covered by the roller is 7 feet 6 inches, and the weight is distributed as follows: On the front rolls one-third of the total weight and on the back rolls two-thirds of the weight, or 5 tons on each wheel. This gives the driving-wheels a compressive force of 5½ cwt. per inch of width, being nearly two and three-quarter times greater than that exerted by the front rolls. The consumption of coal rarely amounts to 6 cwt. per day of 9 hours. The extent of the rolling to be performed in each season is determined early in the year. The several portions of road are divided into sections to suit the various quarries from which the metal is to be taken. Care is exercised in fixing the point in the highway at which the material from two different quarries joins. In doing this, due consideration is given to the nature of the surface of the road over which the material is to be conveyed. Unnecessary lapping is thus avoided, which, besides possessing no advantage, adds to the cost of haulage. The metal is always conveyed to, and the rolling commenced at, the farthest point of the highway from the quarry. This avoids the necessity of the carts employed on the work passing the roller. One ton of metal covers 32 square yards to a thickness of 1 inch. The portion of road coated each day may be checked by referring to the weight-book, when it will be seen whether the desired quantity of metal is being applied.

Two men spread the metal as it is brought from the breaker. The rolling is commenced after a length of between 20 yards and 30 yards of road has been covered with metal. It is worked from the outsides or flanks to the centre and is continued until the coating is well compressed, water being applied meanwhile. The binding-material, preferably loamy sand, is placed along the water-tables. This retains the water, and it is then worked into a grout and is swept from the sides to the centre of the road, filling the voids till the whole coating is consolidated by continued rolling and presents a mosaic-like surface.

Work carried out in this manner gives excellent results. The

stones comprising the coating are wedged together with their flat sides uppermost, and contain only sufficient binding-material to maintain cohesion. Any excess of binding is squeezed out by the passage of the roller and swept to the sides, leaving the metal in a practically solid mass. On breaking up a portion of a rolled road, the quantity of binding-material was found to be barely 15 per cent. of the bulk. Heavy or argillaceous soils should be avoided as a binding-material. They absorb and retain a considerable amount of moisture, which acts adversely on the surface under varying conditions of weather. Clean sand is also unsuitable; it has not sufficient cohesive properties to retain the metal in position. It has the further disadvantage during watering of being washed to the bottom of the metal coating, from which it cannot be recovered, and forming what is termed a "rotten" road. Endeavour should be made each night to roll the coating close up to where the daily supply of metal from the breaker is spread. By this means the least possible inconvenience is caused to the passing traffic. The sweeping is performed by four men, the roller being kept constantly at work.

Artificial watering is necessary, and is best performed by a water-cart with a distributor attached. It sometimes happens that a water-supply is available close to the highway, dispensing with the use of a water-cart. Picking up the old surface, for which spike-holes are provided in the driving-wheels of the roller, is seldom resorted to. Heavy coatings are necessary in the first instance to make a uniformly strong road. The surfaces of old roads, which have become irregular in shape, are picked up, if they contain a sufficient amount of metal, to a depth of 2 inches with hand-picks, or, better still, by a scarifier, and properly formed. A coating one stone thick is then applied, and with watering and rolling a good surface may be obtained. When rolling operations were first carried out in the district of Cupar, stretches of hand-broken metal were laid down alternately with that supplied from the stone-breaking machine. The same method of rolling was observed in each case, and the road when finished looked as if the whole surface had been coated with the same metal. After a few months' wear it was observed that many depressions appeared on the surface. On referring to the particulars taken when the metal was spread, it appeared that the hollows occurred on the portions that had been supplied with hand-broken stone. No fault could be found with the metal; it was well-broken and of good quality. It contained, however, a large quantity of

debris which had fallen or been washed through the larger-sized metal to the bottom, and had been there converted into mud. This conclusively proves the importance of thoroughly screening the metal, and of only applying the binding after the metal has been well set by the repeated passage of the roller. Metal and binding mixed promiscuously and rolled may show a good surface when newly finished, but after a few months' traffic during wet weather the surface falls into an unsatisfactory state. The length of road rolled per day depends on the width of the road and the thickness of the coating applied. The cost in the district referred to averages 8·78*d.* per ton of metal consolidated.

The total cost per ton of metal from the quarry to its consolidation in the road, at 1 mile from the quarry, is as follows:—

	d.
Tirring, or stripping, drilling and blasting[1] . . .	6·00
Breaking	10·25
Haulage, team-work (1 mile from quarry)	7·75
Steam-rolling (including spreading)	8·78
	32·78

NOTE.—7¾*d.* per ton must be added for each additional mile from the quarry.

When the rolling operations are finished for the season the squad of labourers is dispensed with, the foremen only being retained. During the winter months the roller is employed in rubbing in patchwork, when the state of the road-surface permits it. This class of work is not economical. It may smooth the patched portion, making travelling somewhat easier, but at considerable expense in metal. It may be noticed that roads consolidated from the foundation by a steam-roller stand the most severe conditions of alternating frost and thaw. Roads repaired with a coating of metal 3 inches to 4 inches thick rolled by a steam-roller show a slightly disintegrated surface. In cases where the materials used for repairs are of a soft description, or where the road-coating contains a large percentage of detritus or binding, the surface is completely disintegrated by a rapid thaw after frost.

Cleaning the Surface.—The removal of the detritus resulting from the wear of materials occupies an important place in a good

[1] Quarrying work has been recently accomplished for 4·58*d.* per ton.

system of road-maintenance. The detritus is generally removed in the form of mud by hand-scrapers, or horse scraping- and sweeping-machines. The former can only be used to a limited extent, but to properly clean a long section of road the time occupied is such that many changes of weather intervene—stopping, or at all events retarding, the operation. When the mud is sticky, the horse-scraper is used, and immediately after rain the horse-sweeping machine thoroughly cleans the surface of the road. An additional advantage is that a long stretch can be cleaned each day, should the condition of the surface permit. A road between 15 feet and 25 feet wide can be thoroughly cleaned (including repairs to the machine) for 2*s*. per mile. With a hand-scraping machine, under the best conditions of work, the same amount of cleaning will cost 12*s*. The surface of 100 miles of highway can be kept thoroughly in order by the use of one horse-scraper and a sweeping-machine.

The results obtained in carrying out the work by the aid of machinery clearly show its many important economic advantages. In localities where rolled roads have existed for some years, it is stated that the saving in repairs to vehicles, harness, &c., go a long way to meet the road rates, and the haulage of heavy loads is facilitated by a good road-surface. The appearance of the surface of a rolled road, compared with that of a traffic-made road after a long frost, shows that it is less liable to become disintegrated, and consequently it suffers less damage from the passing traffic. This may be easily understood when it is considered that, while the ratio of soft to hard material in a traffic-consolidated road is 40 per cent., in a rolled road it is only 15 per cent. Alternating frost and fresh destroy the solidity and cohesion of a crust which is largely composed of soft material. It often happens that the traffic cuts through the coating, and the crushing and rubbing soon pulverise the material, at the same time throwing the cross section out of shape. It has been estimated that between 15 per cent. and 30 per cent. of the loose metal used in patching is wasted by being ground to dust under the traffic, previous to the consolidation of the coating. Taking the loss at 20 per cent., the value is more than sufficient to provide for efficient rolling. Roads maintained by the old system seldom have a reserve of strength. Fluctuations of traffic often completely destroy the surface, and extensive repairs are necessary. With a rolled road the coating is uniformly strong, and capable of carrying the heaviest traffic without injury to the

surface. Less labour is required in maintaining the surface of a rolled road, and the amount of mud and dust is reduced to a minimum.

In the maintenance of roads, the problem is how to reduce to a minimum the wear and waste resulting from traffic and weather. By the aid of such machinery as has been referred to this may be accomplished most effectually, and in an economical manner.

The Paper is accompanied by a sheet of tracings, from which the *Figs.* have been prepared.

(*Paper No. 2820.*)

"Repairs and Renewals of Railway Rolling-Stock."

By Alfred John Hill, Wh.Sc., Assoc. M. Inst. C.E.

Since the valuable Papers [1] on this subject by Mr. A. McDonnell were communicated to the Institution in 1877 and 1881 many changes affecting the question have taken place, such as the more general adoption of continuous brakes, the increased loads and speeds, the greater importance of punctuality both for passenger and goods trains, the demand for greater comforts and conveniences in the carriages, and higher rates of pay and smaller number of working hours for railway servants.

The Author is of opinion that Mr. McDonnell omitted one important point, viz., the definition of the terms "Repairs and Renewals." He is well aware of the difficulty of giving a clear definition, particularly when the North-Eastern Railway Company, during a period of about twelve years, includes the cost of between three and four hundred locomotives, which had presumably been charged to revenue, in the capital stock without any increase in capital account. The total cost of these locomotives at £2,000 each would be between £600,000 and £800,000. Upon the basis of such a classification, it is extremely difficult to make any definite comparison of the cost of repairs and renewals on different railways. In the Author's opinion the term "Maintenance" might with advantage be substituted for "Repairs and Renewals," for the cost required is that of maintaining the stock in good working order and repair, so that at any time there are sufficient engines and vehicles in a thorough state of efficiency to work the traffic. The word "Maintenance" has therefore been adopted for the Tables in Appendix II. Depreciation funds have almost entirely disappeared from the accounts of the English railway companies, although they were often to be found in earlier reports. Duplicate stock and rolling-stock renewal accounts are sometimes given separately, but the more general

[1] Minutes of Proceedings Inst. C.E. vol. xlviii. p. 2; and vol. lxvi. p. 295.

rule appears to be to include the cost of renewals with that of repairs.

The Author has prepared Tables of the principal figures relating to the cost of repairs and renewals of rolling-stock from the half-yearly reports of twelve of the most important English, together with three Scotch and four Irish railway companies, for a period of five years ending June 1892. In Table I will be found the averages of the principal figures relating to the repairs and renewals, that is the maintenance, of locomotives, for the nineteen railways during the period named. Tables IV to XXII show detailed analyses of most of these averages for each half-year. It will be seen that the average cost of engine maintenance per train-mile on the English lines varies between 4·40*d.* on the North-Eastern Railway and 2·04*d.* on the London and South-Western Railway, and on the Scotch and Irish lines between 2·86*d.* on the Great Southern and Western Railway of Ireland and 1·47*d.* on the North British Railway, the average of the nineteen companies being 2·51*d.* The Author has not been able to subdivide these figures into wages and materials, as the items are not uniformly dealt with by the different companies. For example, the Great Eastern Railway Company made and stored new boilers, fire-boxes, sets of wheels, &c., to be afterwards charged out as material to the individual engines for which they were used, whereas the wages and materials for such articles are now kept distinct, and charged accordingly in the appropriation sheets. Again, some companies roll their own iron and steel bars, plates, tires, &c., and manufacture many other parts, while others buy even their renewal engines. It is therefore evident that any attempt to subdivide the maintenance charges into wages and materials for comparative purposes would be misleading. In comparing the figures collected in the appended Tables, the varying nature of the road, the traffic, and occasionally a difference in the system of arranging the charges must be borne in mind, and these call for some explanatory remarks.

Taking first the North-Eastern Railway Company, as that which expends the largest amount per train-mile upon engine maintenance, it should be noticed that, with the exception of the Midland, this company runs a larger percentage of goods-miles than any other, viz., North-Eastern Railway 57 per cent., Midland Railway 59 per cent., Manchester Sheffield and Lincolnshire Railway 53 per cent., and so on to the minimum of 14 per cent. on the London Chatham and Dover Railway; and the ratio of

mineral to general goods traffic on the North-Eastern Railway is also excessive. Further, as before stated, this company has apparently been building engines to revenue, and afterwards transferring them to capital without anything being credited to repairs and renewals or maintenance.

The Lancashire and Yorkshire Railway Company expends the second largest amount per train-mile upon engine maintenance, viz., 3·38*d.* This is accounted for by the fact that although the Great Northern, Midland, Manchester Sheffield and Lincolnshire, Great Western and London and North-Western Railway companies run a larger percentage of goods-miles than the Lancashire and Yorkshire, the ratio of engine- to train-miles is higher on the Lancashire and Yorkshire than on any other line in England, due, no doubt, to the towns served by that railway being nearer together than on the other systems, the comparative amount of shunting being thus increased. The operation of shunting is included in the engine mileage at the rate of between 4 miles and 8 miles an hour. This is severe work for the locomotive, and to thoroughly enter into the question the percentage of engine- and horse-shunting on the various lines would have to be analysed. As an illustration of how the amount of shunting, &c., may vary on the different sections even of one line, it is found that the percentage of shunting-miles, &c., varies between 5·12 and 13·02 on the total passenger-miles, and between 2·01 and 109·59 on the total goods-miles run in the respective districts on the Great Eastern Railway. It is also difficult to account for the extremely low figure on the North British Railway, viz., 1·47*d.* per train-mile. In making any comparison with the Great Eastern Railway it must be remembered that a large portion of its passenger traffic is run by suburban trains, the continual stopping and starting of which has a material effect upon the repairs of the rolling-stock. It should be noted that the increase in the engine stock of this company during the period considered was larger than that of any other line, viz., 25 per cent.

It is worthy of notice that if the cost of maintenance per engine per annum be taken instead of the cost per train-mile, the order in which the English companies stand is considerably altered. Excluding the North-Eastern Railway, the maximum and minimum costs per train-mile are 3·38*d.* and 2·04*d.* on the Lancashire and Yorkshire and London and South-Western Railways respectively, or about 40 per cent. difference; but, on the other hand, the maximum and minimum costs of maintenance per engine per

annum are £253 and £184 on the Great Western and South-Eastern Railways respectively, or about 27 per cent. difference. There does not appear to be much relation between the cost of maintenance and the number of train-miles per engine. The two companies which show the lowest annual mileage per engine, excluding duplicates, which are not generally shown in the half-yearly reports, are the highest in cost of repairs per train-mile (Appendix II, Table I).

The Author has been able to obtain information relating to the numbers of engines renewed by seven of the English and Scotch railway companies, and Table XXIII shows that the average of renewals was 3·6 per cent. per annum, or equivalent to an average life of about twenty-eight years. This may appear a long life, but in the Author's opinion it is quite impossible to measure the efficiency of the maintenance of locomotives by the percentage of renewals. In one case, a company may have a varied stock of engines which are expensive to maintain in repair, and some of which are possibly quite unsuited to the present traffic, in which case it would be necessary to replace annually a comparatively large number by standard engines. In another case, a company, as for instance the London and North-Western Railway, may possess engines of the several standard types suitable for the traffic, and having details to a great extent interchangeable. In the latter case renewal would only mean replacing an old engine by a new one of practically the same design; and it would be desirable to keep the old engine at work as long as possible, renewing the boiler, cylinders, and other details as each became necessary.

Boilers.—There is no doubt that the more perfect the condition in which a locomotive is kept, the more efficiently and economically can it do its work; and there is probably no part of a locomotive which requires more attention, or which so assuredly repays for that attention, than the boiler. In the Author's opinion an engine will generally outlast two boilers, and every boiler two fire-boxes. As an instance in support of the first of these points, the Great Western Railway Company during the five years ending June 1892 renewed 287 boilers and also 228 engines with boilers complete; while the Great Eastern Railway Company renewed 145 boilers and 141 engines with boilers complete. The average percentage of boilers renewed by these companies during the period named, including those in rebuilt engines, was, on the Great Western Railway 6·2 per cent., and on the Great Eastern

Railway 7 per cent. This is equivalent to a life of 16·1 years and 14·5 years respectively, or, taking the total train-miles run, it represents one boiler renewed on the Great Western Railway for every 328,028 miles, and on the Great Eastern Railway for every 305,055 miles. The Author is not in favour of laying down any definite mileage- or time-limit to the life of a boiler, but he believes it is more economical to renew boilers or fire-boxes, than to be continually patching and repairing them when they are much worn.

On the Great Eastern Railway, fire-boxes are as a rule made of copper, the following being an analysis of a typical plate:—

	Per cent.
Copper	99·510
Arsenic	0·115
Antimony	traces.
Lead	0·135
Bismuth	0·013
Oxygen (combined)	0·095
Iron, silver, &c., by difference	0·132
	100·000

Some chemical analyses of fire-box plates, which had lasted well in service, indicated that a larger percentage of arsenic might be an advantage; and with a view to determine this, several fire-boxes have been made partly of plates having the above composition and partly of plates containing 0·5 per cent. of arsenic. It is interesting to note that Mr. Dean, of the Great Western Railway, has also made investigations with regard to this matter, from which it appears that the experience of the Great Western is much in accordance with that of the Great Eastern Railway Company.[1]

During the past three or four years twenty-five boilers belonging to the latter company, mostly of small size, have been fitted with mild-steel fire-boxes, and have so far given satisfaction; but they have not been sufficiently long in service to justify with certainty the advisability of their extended adoption. These fire-boxes were made of plates $\frac{1}{4}$ inch thick with the exception of the tube-plate, which was rolled $\frac{1}{2}$ inch thick throughout. The tube-area was then dished $\frac{1}{4}$ inch by hydraulic pressure, and the plate planed flat, thus leaving the tube-area $\frac{1}{2}$ inch while the thickness of the

[1] Institution of Mechanical Engineers, Proceedings, 1893, p. 139.

rest of the plate was reduced to $\frac{1}{4}$ inch. The principal reason for copper being generally considered more suitable than steel for locomotive fire-boxes is that its thermal conductivity is 73·6 while that of steel is 11·6. With a view to minimise the disadvantage of using steel, arising from this fact, the fire-boxes referred to were made of $\frac{1}{4}$-inch plates. Special care should be taken to reduce the lap at the joints of steel fire-box plates to the smallest amount consistent with safety. The lateral stays for these fire-boxes are of mild steel 1 inch in diameter, but reduced at the centre to $\frac{3}{4}$ inch. A $\frac{7}{16}$-inch hole is drilled $\frac{7}{8}$ inch deep into each end, and by these holes the stays are expanded in the plates after they have been screwed into position. The Author believes that Mr. J. C. Park, the late locomotive superintendent of the North London Railway, was the first to introduce this method of expanding mild-steel stays. The cost of a steel fire-box, as above described, is about £30, and that of a copper box for a similar boiler is about £90, excluding all items which are common to both steel and copper boxes. The consumption of coal appears to be smaller in the engines with steel fire-boxes than in similar engines having copper fire-boxes.

Lap-welded basic-steel tubes, with 6 inches of brass brazed on at the fire-box end, have been almost exclusively used of late on the Great Eastern Railway. They are as a rule $1\frac{5}{8}$ inch in outside diameter, being secured by steel ferrules at the fire-box end and expanded at the smoke-box end. Tubes of steel throughout have been adopted by other railway companies. They have been tried on the Great Eastern Railway, but considerable difficulty has been experienced in keeping them tight, whereas the brass-ended steel tubes have given practically no trouble. Owing to the difficulty in tracing tubes after they have been taken out for repairs, definite information as to their life cannot be given. Mr. McDonnell, in the Paper referred to,[1] gives the average mileage life of eighteen sets of brass tubes at 276,693 miles. Owing to the increased pressures and increased wear and tear to which locomotives within the Author's observation are subjected, this is a greater average mileage than is now obtained.

Crank-Axles.—All the new crank-axles, used during the last ten years on the Great Eastern Railway, have oval webs hooped with weldless-steel rings; this practice, while adding compara-

[1] Minutes of Proceedings Inst. C.E., vol. lxvi. p. 302.

tively little to the first cost, has been found to eliminate almost entirely the chances of the axle breaking into two pieces while running; and, in the Author's experience, if a flaw exists in the web of a hooped crank, it will spread less rapidly than without the hoop. The Author is of opinion that no definite mileage-limit can be stated for the life of a crank- or other axle, but that if an axle be sound in the first instance it may last, and might safely be used, during the complete lifetime of a locomotive. He believes that every properly designed crank-axle broken in service must have contained some slight original flaw or pinhole, which developed under the strains of ordinary work. This flaw would probably be due either to an airhole in the body of the ingot, or to the ingot itself being too small to allow all the sponginess or piping formed while cooling to be cut away during manufacture. The Author agrees with Mr. J. A. F. Aspinall, M. Inst. C.E.,[1] that if all crank-axles were forged under hydraulic presses instead of steam-hammers there would be more probability of their being absolutely sound; this, however, would not render the precaution of cutting off the end of the ingot less necessary.

Every engine-axle on the Great Eastern Railway after it has run 250,000 miles is subjected to a special examination, for which purpose all encumbrances except wheels and crank-hoops are removed, all paint is scraped off, and the axle is thoroughly cleansed with spirit. A similar examination is made after every additional 100,000 miles has been run. All axles, whether crank or straight, are also specially watched while being turned, and none are used in which the slighest flaw is visible. During the year 1892, thirty-six crank-axles were, for various causes, condemned on this railway, their average service having been about 275,000 miles. In two cases the axles failed while running, but caused no accident to the trains. In thirteen cases flaws were discovered in the shops or running sheds. The remaining twenty-one crank-axles belonged to engines which were either condemned or were being rebuilt with axles of a standard design, but were themselves perfectly sound, the average mileage run by them being 292,619 miles. Appendix I contains particulars of forty crank-axles, ten taken from each of four different classes of engine, viz.: ten No. 1 class, light tender passenger-engine; ten No. 562 class, express engine; ten No. 61 class, passenger tank-engine; ten No. 610 class, six-coupled goods-engine. Five of these axles in each class have been condemned; the average mile

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[1] Minutes of Proceedings Inst. C.E., vol. lxxiii. p. 64.

age of the twenty running on June 30th, 1893, was 447,749 miles, while that of the twenty condemned is 335,098.

An analysis of a crucible-steel crank-axle, in which a flaw was discovered in December 1892, after it had run 513,366 miles, resulted as follows:—

	Per Cent.
Combined carbon	0·550
Silicon	0·238
Sulphur	0·035
Phosphorus	0·020
Manganese	0·303
Iron (by difference)	98·854
	100·000

Two tensile tests were also taken from the same axle with the following results:—

STEEL CRANK-AXLE SUPPLIED BY F. KRUPP IN OCTOBER, 1875.

No. of Test.	Mark on Piece.	Dimensions.		Breaking Load in Tons.		Extension.		Reduction of Area.		Remarks.
		Diameter.	Area.	On Piece.	Per Sq. Inch.	In 4 Ins.	Per Cent.	Diameter.	Per Cent.	
		Inch.	Sq. Inch.			Inch.				
545	B Krupps Crank Axle.[1]	0·995	0·777	29·85	38·42	$\frac{31}{32}$	24·21	0·784	37·84	From axle 876 A.
546	B Krupps Crank Axle.[2]	0·999	0·784	28·62	36·50	$\frac{31}{32}$	24·21	0·776	39·67	Duplicate of No. 545.

The following analysis is taken from a Bessemer-steel crank-axle:—

	Per Cent.
Combined carbon	0·180
Silicon	0·064
Sulphur	0·048
Phosphorus	0·029
Manganese	0·346
Iron (by difference)	99·333
	100·000

The Author is unable to give a tensile test from this axle, but

it would probably stand a load of between 30 tons and 32 tons per square inch.

Tires.—The life of tires must depend greatly upon the nature of the road, as well as upon the description of the traffic worked, and the design of the engine. Unfortunately in deciding upon the section of rail to be used, engineers do not always sufficiently consider the wearing effect which a comparatively sharp-cornered rail has upon the tires. On one line with which the Author is acquainted, the flanges of the tires wear so rapidly that it is often necessary to re-turn the tire before it is appreciably worn upon the tread; and upwards of ½ inch is sometimes turned off the tread in order to bring the flange to its correct form. In considering this question it must be remembered that, in addition to the cost of the tires themselves and of the work entailed in lifting the engine and turning the tires, &c., the engine is for the time thrown out of service. The tires in general use on the Great Eastern Railway are made of Bessemer steel, having a tensile-strength of 40 tons per square inch, and composition shown by the following chemical analysis:—

	Per Cent.
Combined carbon	0·350
Silicon	0·083
Sulphur	0·064
Phosphorus	0·047
Manganese	0·605
Iron (by difference)	98·851
	100·000

With a view to increase the life of tires, and also to decrease the proportion of material which is finally discarded, in comparison with that which is actually worn away, it is desirable that new tires should be made as thick on the tread as can be conveniently arranged consistently with a simple design of spring-gear, &c. The tender-tires on the Great Eastern Railway have therefore recently been made 3½ inches thick, those for the engines being 3 inches thick on the tread. No engine or tender tires are allowed to run when reduced to less than 1⅝ inch in thickness. If, however, when they come into the shop to be turned, it is found that the flange cannot be brought to the right section and leave the tires 1½ inch thick, they are condemned. Engine- and tender-tires may as a rule therefore be considered to be worn out when they are only 1½ inch thick.

The average mileage of ten sets of four-wheels-coupled express-

engine tires on the Great Eastern Railway was found to be as follows:—

—	Leading.	Driving.	Trailing.
Mileage	121,351	194,339	194,339
Miles per $\frac{1}{32}''$ reduction in thickness	2,528	4,049	4,049
Loaded weight on wheels	Tons Cwt. Qrs. 14 8 2	Tons Cwt. Qrs. 14 1 0	Tons Cwt. Qrs. 13 10 3
Diameter of wheel on tread	Ft. 4	Ft. 7	Ft. 7

The average mileage of ten sets of six-wheels-coupled goods-engine tires was found to be as follows:—

—	Leading.	Driving.	Trailing.
Mileage	168,012	168,012	168,012
Miles per $\frac{1}{32}''$ reduction in thickness	3,500	3,500	3,500
Loaded weight on wheels	Tons Cwt. Qrs. 12 8 0	Tons Cwt. Qrs. 14 0 0	Tons Cwt. Qrs. 10 2 0
Diameter of wheel on tread	Ft. Ins. 4 10	Ft. Ins. 4 10	Ft. Ins. 4 10

The average mileage of eight sets of six-wheels-coupled suburban passenger tank-engine tires was found to be as follows:—

—	Leading.	Driving.	Trailing.
Mileage	105,444	105,444	105,444
Miles per $\frac{1}{32}''$ reduction in thickness	2,197	2,197	2,197
Loaded weight on wheels	Tons Cwt. Qrs. 12 17 1	Tons Cwt. Qrs. 13 13 0	Tons Cwt. Qrs. 13 19 3
Diameter of wheel on tread	Ft. 4	Ft. 4	Ft. 4

The average mileage of six sets of tires on six-wheels-coupled tank-engines similar to the above but used for goods trains, and

not fitted with the Westinghouse brake, was found to be as follows:—

—	Leading.	Driving.	Trailing.
Mileage	216,090	216,090	216,090
Miles per $\frac{1}{32}''$ reduction in thickness	4,502	4,502	4,502
Loaded weight on wheels	Tons Cwt. Qrs. 12 4 2	Tons Cwt. Qrs. 13 4 2	Tons Cwt. Qrs. 13 5 2
Diameter of wheels on tread	Ft. 4	Ft. 4	Ft. 4

It will be noticed that the tires of the latter engines ran more than twice the mileage of those of similar engines used for passenger trains. This is no doubt due to the action of the continuous brake, and to the fact that these passenger engines work to a large extent on the Enfield Branch, one of the hardest services on the Great Eastern Railway, where they have to run $10\frac{3}{4}$ miles with fourteen intermediate stops in forty minutes. Seventeen of these passenger tank-engines were fitted in January 1892 with special hard-steel tires having a tensile-strength of 48 tons to the square inch, and the results obtained up to their first turning were satisfactory. The average mileage was 47,134 for an amount of wear equal to $\frac{1}{4}$ inch in thickness, or 5,892 miles per $\frac{1}{32}$-inch reduction. This is nearly three times the duty obtained from the softer tires.

Sixteen pairs of crucible-steel tires have been tried on the driving- and trailing-wheels of the four-coupled express engines. Only one set had worn out by the 31st March, 1893, and these had run 202,623 miles. The average mileage per $\frac{1}{32}$-inch reduction in thickness for the sixteen pairs up to the 31st March, 1893, was 4,715 miles compared with 4,049 miles for the softer tires previously referred to. During the three years 1888–90, the consumption of engine and tender tires for repairs and renewals on the Great Eastern Railway was 3,512, weighing 1,407 tons 8 cwt.; and the engine-miles run (excluding those by "capital" engines) were 58,202,648. This is equivalent to a consumption of 54 lbs. of tire for every 1,000 engine-miles; or taking the average cost of new tires at £10 per ton, and allowing for the credits obtained by the sale of old tires, the cost of engine and tender tires per 1,000 engine-miles was about 4*s.* 4*d.*, or 0·052*d.* per mile.

While fully realizing the importance of the repairs to many other parts of a locomotive, the Author feels that it is impossible to go much farther into detail without considering the question of design more fully than he is prepared to do, or than the subject of the Paper warrants. The Author has also collected statistics of the cost of maintenance of carriages and wagons used on various railways, and these have been arranged in Tables following those relating to locomotives.

In Appendix II will be found twenty-two Tables containing particulars for the five years ending June 1892 of the rolling-stock, including locomotives, carriages and wagons of some of the principal railway companies in the British Isles, together with their cost of maintenance, that is, the cost of repairs and renewals. In Appendix III will be found three Tables showing the proportion of renewals in each class of rolling-stock made by some of the typical railway companies during the same period.

In conclusion, the Author's thanks are due to Mr. James Holden, M. Inst. C.E., locomotive superintendent of the Great Eastern Railway, for his kindness in giving him valuable information and facilities; as well as to various officers of the other railways referred to.

APPENDIXES.

APPENDIX I.

Particulars of Twenty Crank-Axles Broken and Condemned.

No. 1 Class.

Particulars of Crank-Axles.	Date New.	Date condemned.	Age. yrs.	Age. mths.	Mileage.
Passenger Tender.					
2 4-coupled branch, 535*a* . .	Mar., 1875	Oct., 1892	17	7	447,147¾
27 „ „ 2,597*a* . .	Feb., 1877	July, 1893	16	5	400,412
113 „ „ 436*a* . .	July, 1875	Oct., 1891	16	3	376,837¾
48 „ „ 298*a* . .	Nov., 1874	Aug., 1887	12	9	361,268¼
49 „ „ 3,313*a* . .	„ 1878	June, 1890	11	7	357,076½
		Average			388,548½

No. 562 Class.

Particulars of Crank-Axles.	Date New.	Date condemned.	Age. yrs.	Age. mths.	Mileage.
Passenger Tender.					
649 4-coupled express, 6,566*a* . .	Jan., 1883	Oct., 1891	8	9	347,539½
648 „ „ 7,239*a* . .	Oct., „	June, 1890	6	5	248,512¾
569 „ „ 6,827*a* . .	Apr., „	Feb., „	6	10	246,356
565 „ „ 6,688*a* . .	Feb., „	Oct., 1887	4	8	194,384
646 „ „ 7,384*a* . .	Nov., „	Dec., 1886	3	1	139,229¼
		Average			235,204

No. 61 Class.

Particulars of Crank-Axles.	Date New.	Date condemned.	Age. yrs.	Age. mths.	Mileage.
Passenger Tank.					
69 4-coupled bogie, 883*a* . .	Oct., 1875	Oct., 1893	18	0	542,030¾
214 „ „ 1,304*a* . .	Mar., 1876	Sept., „	17	6	511,098
178 „ „ 2,277*a* . .	Apr., 1877	June, „	16	2	475,461
64 „ „ 1,122*a* . .	Dec., 1875	Aug., „	17	8	450,447¼
178 „ „ 2,281 . .	Apr., 1877	Nov., 1890	13	7	424,360½
		Average			480,679

No. 610 Class.

Particulars of Crank-Axles.	Date New.	Date condemned.	Age. yrs.	Age. mths.	Mileage.
Goods Tender.					
629 6-coupled 7,587*a* . .	Mar., 1884	June, 1892	8	3	266,200¾
623 „ 7,478*a* . .	Feb., „	Nov., 1890	6	9	262,625¾
632 „ 7,652*a* . .	Apr., „	June, „	6	2	233,867½
689 „ 8,389*a* . .	Dec., „	July, „	5	7	214,312½
683 „ 8,312*a* . .	„ „	June, „	5	6	202,800½
		Average			235,961

APPENDIX I.—(*continued*).

Particulars of Twenty Crank-Axles still running, June 30, 1893.

No. 1 Class.

Particulars of Crank-Axles.				Date New.	Age. yrs.	mths	Mileage.
Passenger Tender.							
5	4-coupled branch	8,669	Steel	June, 1872	21	0	609,770½
6	,, ,,	561*a*	,, ...	Mar., 1875	18	3	568,557½
44	,, ,,	8,708	,, ...	June, 1872	21	0	562,907¾
114	,, ,,	2,624*a*	,, ...	Sept., 1877	15	9	442,897½
161	,, ,,	3,018*a*	,, ...	Apr., 1878	15	2	417,887
					Average		520,404

No. 562 Class.

Particulars of Crank-Axles.				Date New.	Age. yrs.	mths	Mileage.
Passenger Tender.							
644	4-coupled express	7,335*a*	Steel	Sept., 1883	9	9	402,793¼
571	,, ,,	6,839*a*	,, ...	Apr., ,,	10	2	385,826¼
565	,, ,,	6,853*a*	,, ...	,, ,,	10	2	385,051
645	,, ,,	6,488*a*	,, ...	Nov., 1882	10	7	382,278¾
643	,, ,,	7,419*a*	,, ...	Dec., 1883	9	6	375,780¼
					Average		386,346

No. 61 Class.

Particulars of Crank-Axles.				Date New.	Age. yrs.	mths	Mileage.
Passenger Tank.							
75	4-coupled bogie	904*a*	Steel	Oct., 1875	17	8	534,575¼
215	,, ,,	915*a*	,, ...	,, ,,	17	8	533,550¾
213	,, ,,	895*a*	,, ...	,, ,,	17	8	518,359½
68	,, ,,	1,014*a*	,, ...	Nov., ,,	17	7	511,677
65	,, ,,	1,213*a*	,, ...	Feb., 1876	17	4	485,938½
					Average		516,820

No. 610 Class.

Particulars of Crank-Axles.				Date New.	Age. yrs.	mths	Mileage.
Goods Tender.							
616	6-coupled	7,113*a*	Steel	Aug., 1883	9	8	375,476¾
614	,,	7,040*a*	,, ...	July, ,,	9	11	372,272¾
622	,,	7,468*a*	,, ...	Jan., 1884	9	5	366,643¼
625	,,	7,523*a*	,, ...	Feb., ,,	9	4	364,016½
615	,,	7,169*a*	,, ...	Sept., 1883	9	9	358,696¾
					Average		367,425

APPEN

TABLE I.—PARTICULARS OF AVERAGE ANNUAL EXPENSES CONNECTED

	English.		
Name of Company	G.E.R.	L.C. & D.R.	N.E.R.
Mileage—passenger	10,623,328	3,512,476	10,908,066
„ goods	6,711,438	607,264	14,451,516
Total	17,334,766	4,119,740	25,359,582
Percentage goods-miles	38	14	57
Train-miles per engine	21,718	22,292	16,484
Cost of engine maintenance per train-mile	2·45*d.*	2·63*d.*	4·40*d.*
„ „ maintenance per engine. . . .	£222 0*s.*	£244 0*s.*	£305 4*s.*
Running expenses per train-mile . . .	5·75*d.*	7·06*d.*	6·62*d.*
Stock of engines	800	185	1,529
Percentage increase	25	16	3·6

	English—*continued.*		Scotch.
Name of Company	L. & N. W. R.	L. & Y. R.	G. & S.W.R.
Mileage—passenger	21,000,664	9,363,122	3,081,382
„ goods	19,860,756	6,286,814	2,634,026
Total	40,861,420	15,649,936	5,715,408
Percentage goods-miles	48	40	46
Train-miles per engine	17,570	15,852	19,174
Cost of engine maintenance per train-mile	2·59*d.*	3·38*d.*	1·98*d.*
„ „ maintenance per engine . . .	£189 10*s.*	£223 12*s.*	£160 0*s.*
Running expenses per train-mile . . .	6·13*d.*	6·74*d.*	5·11*d.*
Stock of engines	2,323	987	298
Percentage increase	Nil.	10	3

DIX II.

WITH MAINTENANCE OF ENGINES FOR FIVE YEARS ENDING JUNE, 1892.

English.						
G.N.R.	L. & S.W.R.	S.E.R.	Mid. R.	M.S. & L.R.	G.W.R.	L.B. & S.C.R.
9,683,426	9,119,278	5,717,620	15,361,242	5,465,744	16,834,750	6,742,558
9,466,178	3,503,134	1,571,868	22,678,276	6,306,926	16,952,190	1,498,118
19,149,604	12,622,412	7,289,488	38,039,518	11,772,670	33,786,940	8,240,676
49	27	21	59	53	50	17
23,206	22,632	20,686	20,034	19,978	20,582	21,540
2·20*d.*	2·04*d.*	2·12*d.*	2·63*d.*	3·05*d.*	2·88*d.*	2·30*d.*
£214 0*s.*	£193 8*s.*	£184 0*s.*	£221 0*s.*	£253 4*s.*	£248 12*s.*	£206 6*s.*
5·72*d.*	6·63*d.*	6·68*d.*	6·01*d.*	5·91*d.*	5·52*d.*	6·81*d.*
824	557	352	1,897	590	1,624	410
12	5	13	16	24	5	1

Scotch.		Irish.				Average of all Companies.
C.R.	N.B.R.	M.G.W.R.	G.N.R. of Ireland.	B. & N.C.R.	G.S. & W.R.	
6,546,906	6,855,660	1,314,508	2,029,162	792,596	1,983,966	7,733,497
6,415,062	7,182,404	779,088	932,380	396,252	1,249,970	6,814,929
12,961,968	14,038,064	2,093,596	2,961,542	1,188,848	3,233,936	14,548,426
49	51	37	31	33	38	40
18,792	22,278	19,742	21,616	20,762	18,184	20,164
2·22*d.*	1·47*d.*	2·57*d.*	2·07*d.*	1·96*d.*	2·86*d.*	2·51*d.*
£174 4*s.*	£140 0*s.*	£214 0*s.*	£187 10*s.*	£172 0*s.*	£217 0*s.*	£208 18*s.*
5·23*d.*	4·93*d.*	5·39*d.*	5·28*d.*	5·21*d.*	5·79*d.*	5·92*d.*
690	628	106	137	57	176	..
1	13	10	Nil.	20	1·13	9·4

TABLE II.—PARTICULARS OF AVERAGE ANNUAL EXPENSES CONNECTED

	English.		
Name of Company	G.E.R.	L.C. & D.R.	N.E.R.
Mileage—passenger	10,623,328	3,512,476	10,908,066
„ goods	6,711,438	607,264	14,451,516
Total	17,334,766	4,119,740	25,359,582
Percentage passenger-miles	62	86	43
Passenger-miles per vehicle.	3,096	3,314	3,586
Cost of carriage maintenance per passenger train-mile	2·15*d.*	2·25*d.*	3·03*d.*
Cost of carriage maintenance per vehicle .	£28	£31	£45 6*s.*
Receipts per passenger train-mile . . .	3*s.* 10*d.*	5*s.* 4*d.*	3*s.* 8*d.*
„ vehicle	£586	£886	£664
Stock of carriages	3,431	1,060	3,041
Increase per cent.	21	7	16

	English—*continued.*		Scotch.
Name of Company	L. & N.W.R.	L. & Y.R.	G. & S.W.R.
Mileage—passenger	21,000,664	9,363,122	3,081,382
„ goods	19,860,756	6,286,814	2,634,026
Total	40,861,420	15,649,936	5,715,408
Percentage passenger-miles	52	60	54
Passenger-miles per vehicle	3,648	3,406	3,140
Cost of carriage maintenance per passenger train-mile	3·47*d.*	3·20*d.*	1·94*d.*
Cost of carriage maintenance per vehicle .	£52 14*s.*	£45 10*s.*	£25 10*s.*
Receipts per passenger train-mile . . .	4*s.* 4*d.*	3*s.* 7*d.*	3*s.* 7*d.*
„ vehicle	£788	£620	£516
Stock of carriages	5,754	2,713	980
Increase per cent.	6	7	13

[1] The G.N.R. receipts per train-mile do not include joint lines' receipts, which equal about 7*d.* per net mile, but no distinction is made between passenger and goods.

[2] The M.S. & L. receipts per train-mile do not include joint lines' receipts,

WITH MAINTENANCE OF CARRIAGES FOR FIVE YEARS ENDING JUNE, 1892.

English.						
G.N.R.	L. & S.W.R.	S.E.R.	Mid. R.	M.S. & L.R.	G.W.R.	L.B. & S.C.R.
9,683,426	9,119,278	5,717,620	15,361,242	5,465,744	16,834,750	6,742,558
9,466,178	3,503,134	1,571,868	22,678,276	6,306,926	16,952,190	1,498,118
19,149,604	12,622,412	7,289,488	38,039,518	11,772,670	33,786,940	8,240,676
51	73	79	41	47	50	83
3,850	2,976	2,686	3,816	5,844	3,334	2,606
2·58*d.*	2·10*d.*	2·80*d.*	2·56*d.*	1·11*d.*	2·72*d.*	1·67*d.*
£41 12*s.*	£26 4*s.*	£31 6*s.*	£40 14*s.*	£27 6*s.*	£39 6*s.*	£18 6*s.*
3*s.* 2*d.*[1]	4*s.* 8*d.*	5*s.* 3*d.*	3*s.* 5*d.*	3*s.* 9*d.*[2]	4*s.* 7*d.*	5*s.* 1*d.*
£610[3]	£700	£704	£646	£556[3]	£768	£614
2,514	3,064	2,128	4,024	935	5,046	2,817
9	10	6	22	24	14	Nil

Scotch.		Irish.				Average of all Companies.
C.R.	N.B.R.	M.G.W.R.	G.N.R. of Ireland.	B. & N.C.R.	G.S. & W.R.	
6,546,906	6,856,660	1.314,508	2,029,162	792,596	1,988,966	7,733,497
6,415,062	7,182,404	779,088	932,380	396,252	1,249,970	6,814,929
12,961,968	14,038,064	2,093,596	2,961,542	1,188,848	3,233,936	14,548,426
51	49	63	69	67	62	60
3,864	3,334	3,934	3,924	3,344	3,764	3,550
2·27*d.*	1·68*d.*	2·05*d.*	1·73*d.*	1·80*d.*	2·10*d.*	2·27*d.*
£36 14*s.*	£23 10*s.*	£34	£28 6*s.*	£25 8*s.*	£32 12*s.*	£33 6*s.*
3*s.* 8*d.*	3*s.* 4*d.*	3*s.* 5*d.*	3*s.* 9*d.*	3*s.* 4*d.*	4*s.* 1*d.*	4*s.*
£752	£546	£680	£720	£480	£744	£662
1,694	2,056	334	518	236	527	..
5	10	11	12	27	2	11·6

which equal about 1*s.* 2*d.* per net mile, but no distinction is made between passenger and goods.

[3] In neither of these companies are these receipts from joint lines included in the earnings per vehicle.

TABLE III.—PARTICULARS OF AVERAGE ANNUAL EXPENSES CONNECTED

Name of Company	English.		
	G.E.R.	L.C. & D.R.	N.E.R.
Mileage—passenger	10,623,328	3,512,476	10,908,066
„ goods	6,711,438	607,264	14,451,516
Total	17,334,766	4,119,740	25,359,582
Percentage goods-miles	38	14	57
Goods-miles per vehicle	438	296	182
Cost of wagon maintenance per goods train-mile	2·50*d.*	5·29*d.*	7·30*d.*
Cost of wagon maintenance per vehicle .	£4 12*s.*	£6 10*s.*	£5 10*s.*
Average receipts per goods train-mile . .	5*s.* 1*d.*	9*s.* 2*d.*	6*s.* 3*d.*
„ „ vehicle	£110	£136	£56
Stock of wagons	15,311	2,045	79,366
Increase per cent.	9	0·5	12

Name of Company	English—*continued.*		Scotch.
	L. & N.W.R.	L. & Y.R.	G. & S.W.R.
Mileage—passenger	21,000,664	9,363,122	3,081,382
„ goods	19,860,756	6,286,814	2,634,026
Total	40,861,420	15,649,936	5,715,408
Percentage goods-miles	48	40	46
Goods-miles per vehicle	360	298	208
Cost of wagon maintenance per goods train-mile	1·59*d.*	3·20*d.*	4·13*d.*
Cost of wagon maintenance per vehicle .	£2 4*s.*	£4	£3 12*s.*
Average receipts per goods train-miles .	6*s.* 6*d.*	7*s.* 11*d.*	5*s.* 3*d.*
„ „ vehicle	£118	£118	£52
Stock of wagons	55,126	20,993	12,630
Increase per cent.	12	9	17

[1] The G.N.R. receipts per train-mile do not include joint lines' receipts, which amount to about 7*d.* per net mile, but no distinction is made between passenger and goods.

[2] The M.S. & L.R. receipts do not include joint lines' receipts, which equal

WITH MAINTENANCE OF WAGONS FOR FIVE YEARS ENDING JUNE, 1892.

English.						
G.N.R.	L. & S.W.R.	S.E.R.	Mid. R.	M.S. & L.R.	G.W.R.	L.B. & S.C.R.
9,683,426	9,119,278	5,717,620	15,361,242	5,465,744	16,834,750	6,742,558
9,466,178	3,503,134	1,571,868	22,678,276	6,306,926	16,952,190	1,498,118
19,149,604	12,622,412	7,289,488	38,039,518	11,772,670	33,786,940	8,240,676
49	27	21	59	53	50	17
380	392	306	238	458	400	300
2·13*d.*	3·66*d.*	3·72*d.*	4·88*d.*	1·92*d.*	2·55*d.*	4·10*d.*
£3 8*s.*	£6	£4 14*s.*	£4 16*s.*	£3 12*s.*	£4 6*s.*	£3 12*s.*
4*s.* 8*d.*[1]	5*s.* 8*d.*	7*s.* 2*d.*	5*s.* 3*d.*	5*s.* 5*d.*[2]	5*s.* 3*d.*	7*s.* 11*d.*
£86[3]	£110	£110	£60	£98[3]	£106	£82
24,375	8,934	5,128	95,214	13,762	42,184	7,133
43	12	8	25	24	18	3

Scotch.		Irish.				Average of all Companies.
C.R.	N.B.R.	M.G.W.R.	G.N.R. of Ireland.	B. & N.C.R.	G.S. & W.R.	
6,546,906	6,855,660	1,314,508	2,029,162	792,596	1,983,966	7,733,497
6,415,062	7,182,404	779,088	932,380	396,252	1,249,970	6,814,929
12,961,968	14,038,064	2,093,596	2,961,542	1,188,848	3,233,936	14,548,426
49	51	37	31	33	38	40
140	176	360	264	228	340	303
4·54*d.*	3·42*d.*	2·75*d.*	4·12*d.*	3·75*d.*	3·99*d.*	3·66*d.*
£2 12*s.*	£2 12*s.*	£4	£4 10*s.*	£3 10*s.*	£5 12*s.*	£4 4*s.*
5*s.* 10*d.*	5*s.*	6*s.* 7*d.*	6*s.* 10*d.*	5*s.* 11*d.*	6*s.*	6*s.* 2*d.*
£40	£44	£118	£88	£60	£102	£89
46,800	40,618	2,168	3,517	1,731	3,658	..
18	41	21	6	32	12·5	17·2

about 1*s.* 2*d.* per net mile, but no distinction is made between passenger and goods.

[3] In neither of these companies are these receipts from joint lines included in the earnings per vehicle.

TABLE IV.—PARTICULARS RELATING TO THE GREAT EASTERN RAILWAY.

—	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger	5,220,019	4,742,460	5,334,195	4,800,761	5,571,416	5,030,590	5,830,772	5,157,017	6,011,858	5,417,571
„ goods	3,229,570	3,081,045	3,276,045	3,182,704	3,461,974	3,354,446	3,524,915	3,409,453	3,610,580	3,426,463
Total	8,449,589	7,823,505	8,610,240	7,983,465	9,033,390	8,385,036	9,355,687	8,566,470	9,622,438	8,844,034
Cost of engine maintenance—										
Wages . . . £	55,296	48,323	55,644	49,435	53,179	52,786	60,956	56,094	63,090	60,089
Materials . . . „	26,937	20,949	31,176	23,224	35,233	28,132	37,943	38,549	35,511	36,464
Total [1] . . . „	84,024	71,133	88,658	74,570	90,363	82,909	100,984	96,777	100,726	98,759
Per train-mile . . . d	2·39	2·18	2·47	2·24	2·40	2·37	2·59	2·71	2·51	2·68
Cost of running expenses [1] £	183,765	175,426	186,680	183,266	212,567	205,179	232,929	225,133	241,517	299,174
Ditto per train-mile . . d	5·22	5·38	5·20	5·51	5·65	5·88	5·98	6·31	6·02	6·22
Stock of engines . . .	719	733	745	763	783	803	825	849	879	903
Train-miles per engine . .	11,752	10,673	11,557	10,463	11,537	10,442	11,340	10,090	10,947	9,794
Cost of carriage maintenance—										
Wages . . . £	24,185	22,702	25,930	20,717	27,354	22,012	28,427	24,278	30,178	25,439
Materials . . . „	21,090	14,122	20,573	16,350	27,164	16,946	30,713	21,191	31,869	22,512
Total [2] . . . „	45,872	37,444	47,116	37,704	55,168	39,621	59,835	46,181	62,757	48,686
Per passenger train-mile d	2·11	1·89	2·12	1·88	2·38	1·89	2·46	2·15	2·50	2·16
Stock of carriages . . .	3,125	3,166	3,256	3,311	3,357	3,450	3,528	3,629	3,708	3,785
Cost of wagon maintenance—										
Wages . . . £	15,682	14,727	15,317	14,071	15,815	14,338	16,869	15,607	17,662	15,993
Materials . . . „	21,972	12,856	22,020	11,830	23,407	13,888	29,253	14,624	26,279	12,978
Total [2] . . . „	38,250	28,204	37,950	26,539	39,872	28,889	46,817	30,943	44,651	29,705
Per goods train-mile . d	2·84	2·20	2·78	2·00	2·76	2·07	3·19	2·18	2·97	2·08
Stock of wagons . . .	14,721	14,731	14,821	15,011	15,206	15,385	15,528	15,689	15,904	16,118

[1] Half salaries, &c., included in these totals.

[2] Salaries, &c., included in these totals.

TABLE V.—PARTICULARS RELATING TO THE LONDON, CHATHAM AND DOVER RAILWAY.

—	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger	1,762,757	1,626,489	1,757,334	1,666,755	1,841,701	1,685,878	1,837,331	1,678,139	1,909,258	1,796,738
„ goods	283,983	277,925	299,565	281,793	314,028	301,790	321,728	315,988	330,832	308,691
Total	2,046,740	1,904,414	2,056,899	1,948,548	2,155,729	1,987,668	2,159,059	1,994,127	2,240,090	2,105,429
Cost of engine maintenance—										
Wages . . . £	11,173	9,955	10,885	10,611	11,289	11,043	11,342	11,167	12,254	11,800
Materials . . . „	8,998	9,524	10,463	9,748	11,206	9,990	11,138	10,556	11,085	11,074
Total[1] . . . „	21,209	20,516	22,409	21,364	23,590	22,044	23,538	22,794	24,434	23,964
Per train-mile . . . d	2·48	2·58	2·61	2·63	2·62	2·67	2·61	2·74	2·61	2·73
Cost of running expenses[1] £	53,635	50,683	54,664	52,503	62,891	59,326	69,212	66,112	71,284	67,871
Ditto per train-mile . . d	6·28	6·38	6·38	6·46	7·00	7·16	7·69	7·95	7·63	7·73
Stock of engines	180	180	180	180	180	180	180	180	201	210
Train-miles per engine . .	11,371	10,580	11,427	10,825	11,976	11,042	11,994	11,078	11,144	10,026
Cost of carriage maintenance—										
Wages . . . £	6,789	6,559	6,847	6,965	7,304	7,005	7,655	7,221	7,441	7,552
Materials . . . „	7,543	7,209	7,862	8,614	8,941	9,564	9,667	9,754	10,021	9,848
Total[2] . . . „	14,769	14,212	15,152	16,021	16,704	17,012	17,755	17,458	17,900	17,882
Per passenger train-mile d	2·01	2·09	2·06	2·31	2·17	2·42	2·31	2·49	2·25	2·38
Stock of carriages . . .	1,030	1,040	1,048	1,048	1,048	1,048	1,048	1,078	1,106	1,108
Cost of wagon maintenance—										
Wages . . . £	2,909	2,698	2,840	2,571	2,813	2,485	2,818	2,741	3,137	2,935
Materials . . . „	3,661	3,660	3,607	3,331	3,503	3,450	3,659	3,952	3,494	4,283
Total[2] . . . „	6,789	6,581	6,668	6,124	6,545	6,157	6,693	6,934	6,851	7,460
Per goods train-mile . d	5·73	5·68	5·34	5·21	5·00	4·89	4·99	5·26	4·97	5·80
Stock of wagons	2,035	2,045	2,045	2,045	2,045	2,045	2,045	2,045	2,045	2,045

[1] Half salaries and repairs to shops, &c., included in these totals.

[2] Salaries, &c., included in these totals.

TABLE VI.—PARTICULARS RELATING TO THE NORTH-EASTERN RAILWAY.

—	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger . . .	5,399,845	4,917,972	5,427,242	5,000,127	5,605,772	5,183,391	5,974,172	5,493,159	6,121,797	5,416,854
„ goods	6,844,887	6,757,487	7,174,495	7,144,089	7,611,004	7,400,739	7,791,153	7,468,739	7,750,430	6,314,557
Total . . .	12,244,732	11,675,459	12,601,737	12,144,216	13,216,776	12,584,130	13,765,325	12,961,898	13,872,227	11,731,411
Cost of engine maintenance—										
Wages . . . . . . £	121,027	119,839	121,383	120,720	120,661	123,935	118,642	124,983	127,216	107,663
Materials . . . . . „	92,600	88,688	112,565	112,993	109,039	114,383	113,257	109,836	98,637	71,717
Total[1] . . . . . . „	223,067	218,166	244,085	245,289	241,671	237,350	246,039	247,255	239,313	191,607
Per train-mile . . . d	4·37	4·49	4·65	4·84	4·38	4·52	4·29	4·57	4·13	3·83
Cost of running expenses[1] £	288,511	281,330	297,642	307,197	333,409	387,488	424,881	405,490	427,710	358,954
Ditto per train-mile . . d	5·65	5·79	5·66	6·07	6·05	7·39	7·41	7·51	7·40	7·33
Stock of engines	1,506	1,506	1,506	1,516	1,521	1,526	1,544	1,550	1,560	1,560
Train-miles per engine . .	8,131	7,953	8,368	8,011	8,690	8,246	8,915	8,363	8,892	7,520
Cost of carriage maintenance—										
Wages . . . . . . £	23,681	25,256	24,233	26,876	26,282	26,712	27,700	27,308	30,863	30,042
Materials . . . . . „	41,956	36,137	41,988	40,640	41,799	38,671	42,094	39,980	39,911	41,245
Total[2] . . . . . . „	67,125	62,905	67,742	69,080	69,672	66,883	71,330	68,966	72,347	72,865
Per passenger train-mile d	2·94	3·07	2·99	3·31	2·98	3·09	2·86	3·01	2·83	3·23
Stock of carriages. . . .	2,868	2,898	2,919	2,919	2,959	2,987	3,075	3,176	3,281	3,333
Cost of wagon maintenance—										
Wages . . . . . . £	68,399	64,460	62,546	62,016	62,267	61,717	63,308	60,107	62,813	54,904
Materials . . . . . „	158,213	132,300	149,337	135,489	157,601	182,349	188,662	171,476	161,608	125,546
Total[2] . . . . . . „	229,821	200,008	215,157	200,828	223,203	247,171	255,131	234,700	227,526	183,638
Per goods train-mile . d	8·04	7·10	7·19	6·74	7·04	8·01	7·85	7·54	7·04	6·98
Stock of wagons	75,020	75,024	75,944	77,087	78,903	80,168	81,310	82,391	83,489	84,324

[1] Half salaries, &c., and repairs to shops and sheds, included in these totals.

[2] Salaries, &c., included in these totals.

TABLE VII.—PARTICULARS RELATING TO THE GREAT NORTHERN RAILWAY.

—.	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger	4,793,383	4,439,824	4,830,398	4,565,011	5,006,765	4,663,561	5,140,294	4,803,140	5,283,589	4,891,173
" goods	4,370,452	4,484,607	4,885,604	4,572,346	4,833,438	4,625,999	4,921,861	4,850,694	5,002,591	4,783,301
Total . . .	9,163,835	8,924,431	9,716,002	9,137,357	9,840,203	9,289,560	10,062,155	9,653,834	10,286,180	9,674,474
Cost of engine maintenance—										
Wages . . . . . . £	43,512	43,910	44,086	42,171	43,465	45,742	46,223	47,765	51,301	48,501
Materials . . . . . "	32,953	35,796	40,303	41,722	38,490	36,008	33,993	37,428	39,611	38,197
Total[1] . . . . . . "	82,503	84,287	88,583	88,920	86,522	86,244	85,263	90,298	97,278	91,300
Per train-mile . . . *d*	2·11	2·26	2·23	2·33	2·11	2·22	2·03	2·24	2·27	2·26
Cost of running expenses[1] £	189,332	185.927	197,070	200,428	229,791	231,188	260,670	263,792	274,257	260,391
Ditto per train-mile . . *d*	4·85	5·00	4·97	5·26	5·60	5·97	6·21	6·56	6·40	6·45
Stock of engines	795	798	799	805	812	816	823	840	864	895
Train-miles per engine . .	11,778	11,183	11,910	11,350	12,118	11,384	12,226	11,373	11,905	10,810
Cost of carriage maintenance—										
Wages . . . . . . £	21,714	21,619	22,512	21,979	24,677	22,807	27,157	21,718	26,137	21,677
Materials . . . . . "	26,621	28,844	25,575	27,840	29,356	28,599	33,022	28,358	30,651	25,114
Total[2] . . . . . . "	49,006	51,141	48,786	50,508	54,843	52,107	60,935	50,756	57,530	47,465
Per passenger train-mile *d*	2·45	2·76	2·44	2·65	2·62	2·68	2·84	2·52	2·61	2·32
Stock of carriages . . .	2,450	2,456	2,456	2,466	2,466	2,490	2,509	2,552	2,614	2,689
Cost of wagon maintenance—										
Wages . . . . . . £	15,918	14,883	14,695	14,957	16,399	16,117	16,867	15,897	17,087	16,364
Materials . . . . . "	25,950	24,062	24,022	24,020	23,781	23,043	26,345	25,238	24,807	26,512
Total[2] . . . . . . "	42,469	39,527	39,289	39,562	40,831	39,764	43,797	46,284	44,988	46,020
Per goods train-mile . *d*	2·23	2·11	2·01	2·07	2·02	2·06	2·11	2·29	2·13	2·30
Stock of wagons	21,232	21,409	21,539	22,049	22,928	23,946	25,067	27,152	27,890	30,549

[1] Half salaries, &c., included in these totals.

[2] Salaries, &c., included in these totals.

TABLE VIII.—PARTICULARS RELATING TO THE LONDON AND SOUTH-WESTERN RAILWAY.

—	1887.	1888.		1869.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger . . .	4,382,060	4,200,598	4,469,270	4,280,728	4,711,022	4,495,043	4,861,971	4,581,447	4,926,140	4,688,119
" goods	1,669,222	1,635,122	1,680,201	1,659,120	1,739,892	1,725,475	1,853,626	1,820,308	1,896,942	1,835,769
Total . . .	6,051,282	5,835,720	6,149,471	5,939,848	6,450,914	6,220,518	6,715,597	6,401,755	6,823,082	6,523,888
Cost of engine maintenance—										
Wages . . . . . . £	31,129	28,295	30,174	30,175	29,802	27,240	31,654	27,532	35,832	31,704
Materials . . . . . "	27,587	20,463	23,838	19,918	23,968	19,602	24,244	15,049	26,711	20,737
Total [1] . . . . . . "	59,978	50,016	55,276	51,371	55,098	48,237	57,336	44,167	64,120	54,134
Per train-mile . . . d	2·37	2·05	2·15	2·07	2·04	1·86	2·04	1·65	2·25	1·99
Cost of running expenses [1] £	153,069	146,769	156,190	150,397	176,573	175,642	199,208	194,354	204,423	194,596
Ditto per train-mile . . d	6·07	6·00	6·09	6·07	6·56	6·77	7·13	7·28	7·19	7·15
Stock of engines	548	548	548	550	553	556	561	566	570	575
Train-miles per engine . .	11,042	10,649	11,221	10,800	11,665	11,188	11,970	11,310	11,970	11,345
Cost of carriage maintenance—										
Wages . . . . . . £	..	..	..	19,696	21,928	19,894	22,143	20,689	22,340	21,628
Materials . . . . . "	..	..	..	16,459	20,630	16,653	21,937	19,228	21,113	21,901
Total [2] . . . . . . "	40,307	31,327	39,118	36,743	43,141	37,185	44,735	40,498	44,066	44,093
Per passenger train-mile d	2·20	1·78	2·10	2·06	2·19	1·98	2·21	2·12	2·15	2·26
Stock of carriages . . .	2,897	2,952	3,003	3,023	3,053	3,081	3,120	3,141	3,176	3,199
Cost of wagon maintenance—										
Wages . . . . . . £	..	..	..	10,462	13,490	13,105	13,588	12,839	13,819	11,715
Materials . . . . . "	..	..	..	9,844	15,463	11,972	15,658	14,208	16,877	13,940
Total [2] . . . . . . "	25,164	23,214	28,157	20,893	29,536	25,715	29,899	27,628	31,309	26,215
Per goods train-mile . d	3·62	3·41	4·02	3·02	4·07	3·58	3·87	3·64	3·96	3·43
Stock of wagons	8,399	8,513	8,634	8,834	8,954	9,019	9,136	9,164	9,279	9,416

[1] Half salaries, &c., included in these totals.

[2] Salaries, &c., included in these totals.

TABLE IX.—PARTICULARS RELATING TO THE SOUTH-EASTERN RAILWAY.

—	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger . . .	2,827,258	2,586,875	2,842,555	2,693,527	2,982,740	2,813,445	3,034,588	2,832,744	3,042,428	2,931,942
,, goods	757,077	739,172	769,258	759,336	787,001	760,249	815,792	793,632	855,446	822,378
Total . . .	3,584,335	3,326,047	3,611,813	3,452,863	3,769,741	3,573,694	3,850,380	3,626,376	3,897,874	3,754,320
Cost of engine maintenance—										
Wages . . . . . . £	10,914	11,270	12,687	12,489	13,515	13,775	13,727	13,814	14,409	13,890
Materials . . . . . ,,	12,503	12,704	14,363	17,876	20,618	18,068	20,231	18,399	21,159	20,406
Total[1] . . . . . . ,,	25,152	24,713	28,825	32,092	35,898	33,584	35,737	34,036	37,244	36,172
Per train-mile . . . d	1·68	1·78	1·91	2·23	2·28	2·25	2·22	2·25	2·29	2·31
Cost of running expenses[1] £	86,909	83,580	86,312	87,063	99,866	99,630	126,560	117,235	118,833	118,717
Ditto per train-mile . . d	5·81	6·03	5·73	6·05	6·35	6·69	7·51	7·75	7·31	7·58
Stock of engines	334	338	339	342	352	352	353	359	378	378
Train-miles per engine . .	10,731	9,840	10,654	10,096	10,709	10,152	10,907	10,101	10,311	9,932
Cost of carriage maintenance—										
Wages . . . . . . £	13,724	13,723	14,640	14,349	15,531	14,650	15,968	15,339	16,492	15,976
Materials . . . . . ,,	16,041	17,348	17,657	16,483	17,512	17,673	19,912	17,908	18,703	17,070
Total[2] . . . . . . ,,	30,422	31,719	33,008	31,497	33,793	33,032	36,624	33,999	36,000	33,809
Per passenger train-mile d	2·58	2·94	2·80	2·81	2·71	2·81	2·89	2·88	2·83	2·76
Stock of carriages . . .	2,039	2,038	2,107	2,159	2,161	2,157	2,153	2,151	2,160	2,163
Cost of wagon maintenance—										
Wages . . . . . . £	4,241	3,784	4,062	3,781	4,061	3,809	3,959	3,714	3,824	3,997
Materials . . . . . ,,	7,893	7,393	7,506	8,713	8,187	8,435	7,077	8,738	8,282	8,248
Total[2] . . . . . . ,,	12,391	11,438	11,840	12,755	12,535	12,525	11,325	12,742	12,397	12,533
Per goods train-mile . .	3·79	3·71	3·69	4·03	3·82	3·95	3·33	3·85	3·47	3·65
Stock of wagons . . . d	5,044	5,034	5,019	4,999	4,984	4,974	5,114	5,267	5,377	5,477

[1] Half salaries, &c., included in these totals.

[2] Salaries, &c., included in these totals.

TABLE X.—PARTICULARS RELATING TO THE MIDLAND RAILWAY.

—	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger	7,384,654	6,868,360	7,693,931	7,303,110	8,112,512	7,164,957	8,239,133	7,615,867	8,501,450	7,022,240
,, goods	9,959,115	10,036,159	10,559,932	10,701,965	11,520,433	11,306,058	12,353,688	12,088,126	12,696,862	12,169,046
Total	17,343,769	16,904,519	18,253,863	18,005,075	19,632,945	18,471,015	20,592,821	19,703,993	21,195,312	20,091,286
Cost of engine maintenance—										
Wages . . . £	88,527	89,396	97,293	94,209	97,936	98,128	106,277	103,232	112,541	106,063
Materials . . . ,,	76,342	74,317	89,847	88,889	106,469	97,110	124,917	107,674	126,613	110,860
Total [1] . . . ,,	174,144	172,891	196,485	192,704	214,429	205,139	251,446	231,407	250,755	228,047
Per train-mile . . d	2·40	2·45	2·58	2·56	2·61	2·66	2·81	2·69	2·83	2·72
Cost of running expenses[1] £	390,506	376,566	402,424	400,314	483,167	472,002	559,922	555,299	589,716	568,073
,, per train-mile . d	5·40	5·34	5·29	5·33	5·90	6·14	6·52	6·76	6·67	6·78
Stock of engines . . .	1,795	1,807	1,822	1,834	1,844	1,886	1,926	1,956	2,020	2,087
Train-miles per engine . .	9,662	9,355	10,018	9,817	10,646	9,793	10,692	10,073	10,494	9,627
Cost of carriage maintenance—										
Wages . . . £	31,144	32,243	30,936	32,385	32,773	33,000	36,948	32,535	38,704	40,724
Materials . . . ,,	43,831	43,116	45,862	42,886	44,964	44,225	44,907	45,631	44,887	46,235
Total [2] . . . ,,	77,742	78,154	79,621	78,148	81,483	80,269	85,496	81,655	87,300	90,858
Per passenger train-mile d	2·52	2·73	2·48	2·56	2·41	2·68	2·49	2·57	2·46	2·75
Stock of carriages . . .	3,689	3,774	3,833	3,854	3,932	4,010	4,049	4,208	4,389	4,510
Cost of wagon maintenance—										
Wages . . . £	64,186	70,733	64,771	70,827	72,221	71,679	72,160	71,015	71,699	72,945
Materials . . . ,,	144,874	160,867	155,596	173,323	157,809	170,706	152,815	160,851	100,718	139,806
Total [2] . . . ,,	212,056	234,498	223,541	247,234	234,142	245,621	228,945	235,631	216,497	216,972
Per goods train-mile . d	5·11	5·60	5·07	5·54	4·87	5·21	4·44	4·67	4·09	4·27
Stock of wagons . . .	86,220	87,348	89,143	89,551	91,552	93,982	98,668	102,915	104,908	107,858

[1] Half salaries, &c., repairs to buildings and gas, included in these totals.
[2] Salaries, and one-half repairs to buildings and gas, included in these totals.

TABLE XI.—PARTICULARS RELATING TO THE MANCHESTER, SHEFFIELD AND LINCOLNSHIRE RAILWAY.

—	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger . . .	2,754,705	2,549,269	2,675,305	2,585,277	2,753,735	2,654,134	2,848,080	2,712,343	2,935,367	2,860,314
" goods	2,918,933	2,813,697	3,002,281	3,001,629	3,264,912	3,128,153	3,341,597	3,232,135	3,465,305	3,365,989
Total . . .	5,673,638	5,362,966	5,677,586	5,586,906	6,018,647	5,782,287	6,189,677	5,944,478	6,400,872	6,226,303
Cost of engine maintenance—										
Wages . . . . . . £	39,417	40,229	42,238	41,155	45,551	43,317	46,012	44,938	49,367	43,397
Materials . . . . . "	29,301	24,629	26,192	27,154	30,165	29,245	30,934	29,555	30,269	31,616
Total[1] . . . . . . "	70,860	67,084	70,587	70,409	77,862	74,715	79,212	76,879	82,096	77,410
Per train-mile . . . *d*	3·13	3·00	2·98	3·02	3·10	3·10	3·07	3·10	3·07	2·98
Cost of running expenses[1] £	116,334	113,203	120,408	122,850	144·190	150,646	171,036	167,731	176,484	176,182
Ditto per train-mile . . *d*	4·92	5·06	5·09	5·27	5·74	6·25	6·63	6·77	6·61	6·79
Stock of engines	545	549	553	557	563	566	600	645	655	676
Train-miles per engine . .	10,410	9,768	10,267	10,030	10,690	10,216	10,316	9,216	9,772	9,210
Cost of carriage maintenance—										
Wages . . . . . . £	9,060	7,881	8,645	6,625	9,024	7,311	8,975	7,906	7,438	7,016
Materials . . . . . "	2,704	4,203	3,054	5,493	3,012	5,423	3,174	4,980	5,261	6,288
Total[2] . . . . . . "	12,139	12,511	12,120	12,585	12,441	13,154	12,558	13,354	13,186	13,804
Per passenger train-mile *d*	1·05	1·17	1·08	1·16	1·08	1·18	1·05	1·18	1·07	1·15
Stock of carriages. . . .	863	877	878	880	900	926	950	980	1,028	1,070
Cost of wagon maintenance—										
Wages . . . . . . £	13,866	11,551	13,276	12,009	12,827	12,328	14,228	13,508	14,393	14,747
Materials . . . . . "	10,976	12,392	11,414	12,047	12,274	12,144	11,153	11,342	11,215	9,978
Total[2] . . . . . . "	25,267	24,378	25,096	24,493	25,515	24,881	25,876	25,342	26,107	25,235
Per goods train-mile . *d*	2·07	2·07	2·00	1·99	1·87	1·90	1·87	1·88	1·80	1·80
Stock of wagons	12,800	12,800	12,810	12,983	13,323	13·681	13,928	14,331	15·092	15,873

[1] Half salaries, &c., included in these totals.

[2] Salaries, &c., included in these totals.

TABLE XII.—PARTICULARS RELATING TO THE GREAT WESTERN RAILWAY.

—	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger . . .	7,906,754	7,420,925	8,115.065	7,698,197	8,682,231	8,140,405	9,160,243	8,537,396	9,622,705	8,889,805
,, goods	7,858,375	7,829,841	8,072,766	8,137,606	8,528,858	8,441,740	8,842,633	8,851,194	9,157,485	9,040,459
Total . . .	15,765,129	15,250,766	16,187,831	15,835,803	17,211,089	16,582,145	18,002,876	17,388,590	18,780,190	17,930,264
Cost of engine maintenance—										
Wages . . . . . . £	113,520	107,815	110,732	106,369	118,002	109,147	119,665	115,786	123,570	120,662
Materials . . . . . ,,	69,817	71,958	69,189	71,982	76,094	75,101	79,949	82,457	84,810	91,517
Total[1] . . . . . . ,,	193,780	190,792	190,712	189,465	205,020	195,695	210,927	209,651	219,799	223,388
Per train-mile . . . d	2·95	3·00	2·82	2·87	2·85	2·83	2·81	2·89	2·80	2·99
Cost of running expenses[1] £	303,926	303,807	321,962	334,577	388,669	398,131	453,734	462,931	479,273	468,966
Ditto per train-mile . . d	4·62	4·78	4·77	5·07	5·41	5·76	6·04	6·38	6·12	6·27
Stock of engines	1,600	1,600	1,600	1,607	1,620	1,620	1,620	1,640	1,660	1,680
Train-miles per engine . .	9,853	9,531	10,117	9,854	10,624	10,235	11,112	10,602	11,313	10,672
Cost of carriage maintenance—										
Wages . . . . . . £	43,648	45,368	50,826	48,349	50,822	47,125	47,256	43,819	47,944	48,156
Materials . . . . . ,,	37,916	33,263	39,007	45,638	54,070	47,702	56,529	51,581	55,730	63,661
Total[2] . . . . . . ,,	84,422	81,666	93,197	97,675	108,512	98,602	107,333	99,091	107,275	115,850
Per passenger train-mile . d	2·56	2·64	2·75	2·91	2·99	2·97	2·81	2·78	2·67	3·12
Stock of carriages . . .	4,679	4,740	4,816	4,870	4,973	5,096	5,213	5,321	5,399	5,357
Cost of wagon maintenance—										
Wages . . . . . . £	38,189	43,095	40,745	38,785	36,858	40,701	38,881	42,693	40,696	39,057
Materials . . . . . ,,	37,796	38,426	39,328	43,841	44,054	51,307	51,241	61,585	54,549	53,187
Total[2] . . . . . . ,,	78,590	84,458	83,077	85,812	83,891	95,493	93,368	107,823	98,501	95,837
Per goods train-mile . . d	2·40	2·59	2·46	2·53	2·35	2·71	2·53	2·92	2·58	2·43
Stock of wagons	38,317	38,859	39,687	41,153	42,299	43,053	43,584	44,566	45,138	45,203

[1] Half salaries, &c., repairs to sheds, &c., and one quarter gas included in these totals.
[2] Salaries, &c., and one quarter gas included in these totals.

TABLE XIII.—PARTICULARS RELATING TO THE LONDON, BRIGHTON AND SOUTH COAST RAILWAY.

—	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger	3,510,686	3,321,160	3,674,447	3,509,956	3,873,090	3,595,905	3,920,364	3,646,157	3,960,851	3,700,174
„ goods	719,833	707,598	725,445	719,344	746,871	732,485	773,323	766,537	804,328	794,800
Total	4,230,519	4,028,758	4,399,892	4,229,300	4,619,961	4,328,390	4,693,687	4,412,694	4,765,179	4,494,974
Cost of engine maintenance—										
Wages[2] £	22,192	24,285	25,381	26,283	27,891	27,627	28,642	26,082	27,997	26,144
Materials „	13,005	11,048	12,694	17,361	13,848	17,414	16,152	17,557	16,513	17,317
Total[1] „	36,026	36,151	38,916	44,421	42,518	45,786	45,510	44,433	45,275	44,249
Per train-mile d	2·04	2·15	2·12	2·52	2·20	2·59	2·35	2·41	2·28	2·36
Cost of running expenses[1] £	108,225	105,091	111,419	106,815	129,163	125,024	144,387	140,471	147,759	138,294
Ditto per train-mile d	6·13	6·26	6·07	6·06	6·70	7·07	7·38	7·64	7·44	7·38
Stock of engines	410	410	410	410	410	410	410	410	410	414
Train-miles per engine	10,318	9,826	10,731	10,315	11,268	10,557	11,448	10,762	11,622	10,857
Cost of carriage maintenance—										
Wages £	11,758	12,388	12,213	11,594	13,723	11,628	13,172	12,900	13,569	14,183
Materials „	11,369	11,476	12,127	9,287	11,066	11,447	14,059	13,029	13,748	15,715
Total[2] „	23,885	24,612	25,114	21,594	25,498	23,762	27,893	26,664	28,021	30,626
Per passenger train-mile d	1·63	1·77	1·64	1·47	1·56	1·58	1·70	1·75	1·69	1·98
Stock of carriages	2,817	2,817	2,817	2,817	2,817	2,817	2,817	2,817	2,817	2,817
Cost of wagon maintenance—										
Wages £	4,972	4,980	5,166	4,832	4,910	5,196	5,254	5,291	5,500	5,950
Materials „	7,193	8,451	5,921	6,266	6,249	6,334	7,217	7,978	8,712	8,658
Total[2] „	12,544	13,806	11,474	11,455	11,513	11,773	12,802	13,637	14,564	14,972
Per goods train-mile d	4·18	4·68	3·79	3·82	3·70	3·85	3·95	4·27	4·34	4·52
Stock of wagons	7,083	7,084	7,085	7,077	7,077	7,077	7,128	7,178	7,245	7,298

[1] Half salaries, &c., included in these totals.

[2] Salaries, &c., included in these totals.

TABLE XIV.—PARTICULARS RELATING TO THE

—	1887. December.	1888. June.	1888. December.	1889. June.
Mileage—passenger . . .	10,407,519	9,367,444	10,508,380	9,626,511
" goods	9,382,625	9,115,238	9,649,943	9,619,536
Total . . .	19,790,144	18,482,682	20,158,323	19,246,047
Cost of engine maintenance—	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Wages	97,688 18 3	89,989 8 10	99,199 15 0	95,605 16 8
Materials	111,801 15 8	105,953 8 9	97,254 13 0	113,921 4 7
Total[1]	230,241 17 7	212,524 19 5	216,555 3 11	226,292 13 11
Per train-mile . . . d	2·79	2·76	2·57	2·82
Cost of running expenses[1] .	420,109 13 6	419,718 1 1	432,343 9 3	435,553 4 0
Ditto per train-mile . . d	5·09	5·45	5·14	5·43
Stock of engines	2,323	2,323	2,323	2,323
Train-miles per engine . .	8,519	7,956	8,678	8,285
Cost of carriage maintenance—	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Wages	46,367 5 2	45,778 18 9	46,554 12 11	46,188 13 2
Materials	98,656 9 7	87,092 15 7	107,058 15 7	88,789 6 10
Total[1]	146,917 4 1	134,810 17 2	155,595 11 7	137,045 18 5
Per passenger train-mile d	3·38	3·45	3·55	3·41
Stock of carriages . . .	5,602	5,602	5,634	5,684
Cost of wagon maintenance—	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Wages	20,689 9 9	21,148 4 0	20,135 18 8	20,324 17 5
Materials	52,435 0 8	42,253 14 3	47,085 0 11	38,361 15 8
Total[1]	75,521 16 6	66,790 10 5	69,629 9 5	61,140 3 1
Per goods train-mile . d	1·92	1·75	1·73	1·52
Stock of wagons	52,458	52,580	52,929	53,540

[1] Half salaries, &c., and half special expenditure taken in each of these totals.

LONDON AND NORTH-WESTERN RAILWAY.

1889.	1890.		1891.		1892.
December.	June.	December.	June.	December.	June.
11,145,826	10,210,605	11,400,894	10,271,201	11,562,323	10,502,621
10,152,015	9,923,703	10,364,208	10,124,885	10,535,980	10,235,654
21,297,841	20,134,308	21,765,102	20,396,086	22,098,303	20,738,275
£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
100,479 4 2	97,582 10 11	100,578 15 9	94,456 9 7	97,958 19 7	94,244 15 5
104,292 14 5	108,074 4 9	96,084 19 9	109,423 0 2	100,073 1 4	105,751 5 9
223,911 13 6	222,001 12 10	214,916 0 6	220,730 19 11	216,644 7 1	217,488 0 9
2·52	2·64	2·37	2·59	2·35	2·51
502,517 1 10	533,661 11 7	617,613 17 10	635,426 18 3	629,940 16 7	613,602 13 9
5·66	6·36	6·81	7·47	6·84	7·10
2,323	2,323	2,323	2,323	2,323	2,323
9,168	8,667	9,369	8,780	9,513	8,927
£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
51,008 18 11	47,362 5 0	52,612 18 4	50,076 15 10	56,229 3 6	53,834 14 4
102,735 19 1	92,780 12 10	105,069 17 11	101,085 3 8	110,276 14 0	107,165 0 2
155,899 4 6	142,331 3 3	159,994 5 3	153,596 9 8	168,913 10 8	163,572 12 11
3·35	3·34	3·36	3·58	3·50	3·74
5,724	5,764	5,828	5,868	5,878	5,956
£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
20,123 14 10	20,996 8 10	21,566 8 8	21,413 15 2	22,318 8 10	22,597 14 6
46,189 12 1	36,911 16 5	41,212 15 10	41,723 10 1	39,745 8 5	37,107 3 7
68,798 13 9	60,407 1 4	65,294 2 9	65,676 12 3	64,617 13 5	62,282 1 5
1·62	1·46	1·51	1·55	1·47	1·46
54,128	54,990	56,181	57,315	58,150	58,994

[2] Salaries, &c., included in these totals.

TABLE XV.—PARTICULARS RELATING TO THE LANCASHIRE AND YORKSHIRE RAILWAY.

—	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger . . .	4,503,251	4,208,153	4,477,689	4,292,748	5,020,894	4,706,533	5,101,522	4,674,347	5,144,784	4,685,697
„ goods	3,113,407	3,023,306	3,056,012	3,017,737	3,204,362	3,133,689	3,279,157	3,185,772	3,282,190	3,138,441
Total . . .	7,616,658	7,231,459	7,533,701	7,310,485	8,225,256	7,840,222	8,380,679	7,860,119	8,426,974	7,824,138
Cost of engine maintenance—										
Wages [1] . . . . . . £	58,495	55,670	60,994	55,743	64,714	61,942	59,340	62,449	69,675	63,612
Materials [1] . . . . . „	48,878	40,672	46,620	43,061	46,769	46,459	48,805	46,423	42,140	49,441
Total [2] . . . . . . „	110,660	101,758	110,080	101,568	114,202	111,304	109,060	113,783	115,077	115,978
Per train-mile . . . d	3·48	3·37	3·50	3·33	3·33	3·40	3·12	3·46	3·27	3·55
Cost of running expenses [2] £	191,433	185,895	179,081	179,780	215,138	223,706	259,723	256,623	262,795	253.885
Ditto per train-mile . . d	6·03	6·16	5·70	5·90	6·27	6·83	7·43	7·83	7·48	7·78
Stock of engines	948	948	967	978	978	978	997	1,009	1,029	1,041
Train-miles per engine . .	8,034	7,628	7,790	7,475	8,410	8,016	8,405	7,790	8,189	7,516
Cost of carriage maintenance—										
Wages [1] . . . . . . £	37,755	38,456	37,784	35,571	34,711	37,696	33,743	32,820	34,260	34,511
Materials [1] . . . . . „	27,814	26,870	30,065	26,675	24,167	26,753	24,609	23,752	26,560	24,453
Total [3] . . . . . . „	66,454	66,172	68,662	62,838	59,697	63,522	59,123	57,324	61,574	59,756
Per passenger train-mile d	3·54	3·77	3 68	3·51	2·85	3·09	2·78	2·94	2·87	3·06
Stock of carriages . . .	2,641	2,665	2,665	2,673	2,673	2,673	2,714	2,779	2,827	2,827
Cost of wagon maintenance—										
Wages [1] . . . . . . £	21,744	21,370	22,038	21,996	22,841	19,497	20,498	21,847	22,424	22,907
Materials [1] . . . . . „	18,706	17,384	16,179	16,300	16,174	21,425	19,490	22,639	21,772	24,059
Total [3] . . . . . . „	41,377	39,683	39,121	39,214	39,910	41,790	40,852	45,358	45,057	47,853
Per goods train-mile . d	3.18	3·15	3·07	3·11	2·98	3·20	2·99	3·41	3·29	3·65
Stock of wagons	20,383	20,443	20,443	20,469	20,481	20,901	21,154	21,482	21,923	22,252

[1] Half fixed charges for renewals included in these totals. [2] Half salaries, &c., included in these totals. [3] Salaries, &c., included.

TABLE XVI.—PARTICULARS RELATING TO THE GLASGOW AND SOUTH-WESTERN RAILWAY.

—		1888.		1889.		1890.		1891.		1892.	
		January.	July.	January.	July.	January.	July.	January.	July.	January.	July.
Mileage—passenger		1,413,397	1,438,909	1,525,956	1,506,767	1,552,539	1,527,318	1,569,982	1,573,509	1,622,748	1,675,792
,, goods		1,236,382	1,217,098	1,311,882	1,321,971	1,336,814	1,333,872	1,303,514	1,332,449	1,352,379	1,423,770
Total		2,649,779	2,656,007	2,837,838	2,828,738	2,889,353	2,861,190	2,873,496	2,905,958	2,975,127	3,099,562
Cost of engine maintenance—											
Wages	£	11,222	12,182	11,588	11,967	11,443	12,555	12,590	13,119	12,314	14,003
Materials	,,	8,668	9,778	8,203	10,350	9,131	9,429	10,526	8,708	10,398	10,924
Total[1]	,,	21,673	23,813	21,818	23,907	22,361	23,663	25,029	23,811	24,903	27,168
Per train-mile	d	1·95	2·15	1·83	2·02	1·85	1·98	2·09	1·96	1·94	2 10
Cost of running expenses[1]	£	50,157	49,494	51,628	51,931	59,572	64,353	72,242	70,605	70,356	71,772
Ditto per train-mile	d	4·54	4·47	4·36	4·40	4·90	5·30	6·03	5·83	5·67	5·55
Stock of engines		291	291	291	301	301	301	301	301	301	301
Train-miles per engine		9,105	9,127	9,752	9,397	9,600	9,508	9,546	9,654	9,884	10,297
Cost of carriage maintenance—											
Wages	£	5,068	5,416	5,435	5,671	6,175	6,621	5,371	5,348	5,380	6,332
Materials	,,	6,004	5,969	6,110	6,235	6,691	7,052	6,604	7,380	6,311	6,385
Total[2]	,,	11,439	11,758	11,926	12,283	13,254	14,051	12,351	13,096	12,071	13,107
Per passenger train-mile	d	1·94	1·95	1·84	1·95	2·04	2·20	1·88	1·99	1·78	1·87
Stock of carriages		928	942	955	974	978	978	987	1,003	1,012	1,047
Cost of wagon maintenance—											
Wages	£	7,294	7,516	7,228	7,831	7,362	7,900	7,535	7,867	7,793	8,653
Materials	,,	13,882	14,395	13,567	15,193	14,243	14,096	12,986	13,801	13,027	13,693
Total[2]	,,	22,266	23,012	21,918	24,118	22,714	23,092	21,621	22,760	21,969	23,527
Per goods train-mile	d	4·32	4·53	4·00	4·37	4·07	4·15	3·98	4·09	3·89	3·96
Stock of wagons		11,743	11,843	11,969	12,113	12,363	12,589	12,887	13,341	13,639	13,818

[1] Half salaries, &c., included in these totals.

[2] Salaries, &c., included in these totals.

TABLE XVII.—PARTICULARS RELATING TO THE CALEDONIAN RAILWAY.

—	1888.		1889.		1890.		1891.		1892.	
	January.	July.	January.	July.	January.	July.	January.	July.	January.	July.
Mileage—passenger . . .	2,948,525	2,931,604	3,074,177	3,062,339	3,269,567	3,236,573	3,558,192	3,551,821	3,607,540	3,524,199
„ goods	3,079,170	2,990,526	3,134,452	3,113,970	3,232,557	3,235,405	3,154,016	3,361,165	3,395,372	3,378,681
Total . . .	6,027,695	5,922,130	6,208,629	6,176,309	6,502,124	6,471,978	6,712,208	6,912,986	7,002,912	6,902,880
Cost of engine maintenance—										
Wages . . . . . . £	27,237	26,017	26,876	23,821	26,358	24,763	29,955	25,317	27,755	25,167
Materials . . . . . „	35,162	25,015	27,977	24,263	29,148	25,235	32,888	31,549	31,085	31,785
Total[1] ([2]) . . . . . „	66,744	55,357	59,229	53,386	59,848	54,333	67,418	61,217	62,964	61,081
Per train-mile . . . *d*	2·65	2·24	2·28	2·07	2·20	2·01	2·41	2·12	2·15	2·12
Cost of running expenses[1] £	109,361	105,146	114,083	114,570	136,711	150,596	169,422	180,959	174,118	170,953
Ditto per train-mile . . *d*	4·35	4·26	4·40	4·45	5·04	5·58	6·05	6·28	5·96	5·94
Stock of engines	690	690	690	690	690	690	690	690	690	696
Train-miles per engine . .	8,735	8,582	8,998	8,951	9,423	9,379	9,727	10,019	10,149	9,918
Cost of carriage maintenance—										
Wages . . . . . . £	8,413	10,814	10,406	11,671	12,000	11,431	12,782	12,864	11,790	12,278
Materials . . . . . „	15,928	15,767	18,509	17,456	19,184	17,944	22,205	21,048	20,808	20,272
Total[3] . . . . . . „	27,796	27,051	29,405	29,722	30,893	29,980	35,726	34,500	33,058	32,997
Per passenger train-mile £	2·26	2·21	2·29	2·32	2·26	2·22	2·40	2·33	2·19	2·24
Stock of carriages . . .	1,668	1,668	1,675	1,675	1,675	1,680	1,687	1,731	1,731	1,758
Cost of wagon maintenance—										
Wages . . . . . . £	17,944	16,171	15,923	16,466	16,682	16,336	15,872	16,029	15,045	16,358
Materials . . . . . „	40,792	42,283	40,928	42,743	41,843	43,354	48,025	43,295	45,488	44,071
Total[3] . . . . . . „	59,492	59,221	57,641	60,210	59,552	60,703	65,180	60,336	61,265	61,141
Per goods train-mile . *d*	4·63	4·75	4·41	4·64	4·42	4·50	4 95	4·30	4·33	4·34
Stock of wagons	44,454	44,454	44,604	44,786	45,477	46,077	46,748	48,156	50,849	52,404

[1] Half salaries, &c., included in these totals. [2] Including alteration to shops. [3] Salaries, &c., included in these totals.

TABLE XVIII.—PARTICULARS RELATING TO THE NORTH BRITISH RAILWAY.

—	1887.	1888.		1889.		1890.		1891.		1892.
	July.	January.	July.	January.	July.	January.	July.	January.	July.	January.
Mileage—passenger . . .	2,988,082	3,206,110	3,181,983	3,298,891	3,213,233	3,316,989	3,508,531	3,806,625	3,829,922	3,927,934
„ goods	3,320,952	3,473,292	3,450,043	3,614,886	3,547,345	3,735,353	3,724,451	3,417,367	3,758,787	3,869,552
Total . . .	6,309,034	6,679,402	6,632,026	6,913,777	6,760,578	7,052,342	7,232,982	7,223,992	7,588,709	7,797,486
Cost of engine maintenance—										
Wages . . . . . . £	23,404	23,679	23,790	24,129	24,236	24,333	24,852	25,154	25,385	25,901
Materials . . . . . „	13,904	16,183	14,757	17,059	15,675	18,977	17,245	19,904	19,692	20,814
Total [1] . . . . . . „	38,654	41,502	40,525	42,543	41,842	44,512	43,505	44,693	46,642	49,418
Per train-mile . . . d	1·47	1·49	1·46	1·47	1·48	1·51	1·44	1·48	1·47	1·49
Cost of running expenses [1] £	116,288	120,184	120,322	125,649	128,175	145,246	155,354	168,940	188,512	185,449
Ditto per train-mile . . d	4·42	4·31	4·36	4·36	4·55	4·94	5·15	5·61	5·96	5·64
Stock of engines	597	603	610	610	618	628	638	648	658	677
Train-miles per engine . .	10,568	11,077	10,872	11,334	10,939	11,070	11,337	11,148	11,533	11,517
Cost of carriage maintenance—										
Wages . . . . . . £	9,765	9,860	10,838	10,221	11,055	10,717	12,124	10,815	12,834	11,707
Materials . . . . . „	12,935	8,786	14,314	9,388	15,346	10,723	16,459	11,639	18,442	12,515
Total [2] . . . . . . „	22,830	18,780	25,286	19,745	26,538	21,579	28,724	22,621	31,466	24,397
Per passenger train-mile d	1·83	1·40	1·81	1·43	1·98	1·56	1·96	1·42	1·97	1·49
Stock of carriages . . .	1,958	1,979	1,988	2,001	2,041	2,081	2,093	2,114	2,140	2,171
Cost of wagon maintenance—										
Wages . . . . . . £	18,619	18,108	18,072	19,068	18,554	20,526	20,806	21,321	21,788	22,399
Materials . . . . . „	28,478	29,456	25,636	30,519	27,473	33,358	30,511	35,279	33,730	37,273
Total [2] . . . . . . „	47,358	47,832	43,977	49,860	46,300	54,163	51,600	56,934	55,896	60,020
Per goods train-mile . d	3·42	3·30	3·06	3·31	3·13	3·48	3·32	3·99	3·56	3·72
Stock of wagons	33,386	33,811	35,968	38,215	39,718	42,376	43,895	45,368	46,015	47,434

[1] Half salaries, &c., also half repairs to shops and sheds, included in these totals.

[2] Salaries, &c., included in these totals.

TABLE XIX.—PARTICULARS RELATING TO THE MIDLAND GREAT WESTERN RAILWAY OF IRELAND.

—	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger	666,293	654,248	660,314	660,998	664,917	641,617	660,046	656,506	660,051	647,555
" goods	369,250	350,673	369,335	352,226	394,368	396,702	412,916	390,972	434,549	404,456
Total	1,035,543	1,004,921	1,029,649	1,013,224	1,059,285	1,038,319	1,072,962	1,047,478	1,094,600	1,052,011
Cost of engine maintenance—										
Wages £	6,648	6,019	6,171	5,957	6,131	6,146	5,455	6,608	6,880	7,180
Materials "	4,450	4,364	4,600	4,594	4,194	4,341	4,163	5,588	4,768	5,604
Total[1] "	11,338	10,631	10,986	10,793	10,546	10,743	9,899	12.481	11,934	13,086
Per train-mile d	2·62	2·53	2·55	2·55	2·38	2·48	2·21	2·86	2·61	2·98
Cost of running expenses[1] £	17,705	18,691	19,977	19,373	23,695	25,316	28,208	28,395	28,360	26,943
Ditto per train-mile d	4·10	4·36	4·65	4·58	5·36	5·83	6·30	6·46	6·21	6·14
Stock of engines	104	104	104	104	104	104	105	105	111	114
Train-miles per engine	9,957	9,962	9,900	9,742	10,185	9,983	10,219	9,976	9,861	9,228
Cost of carriage maintenance—										
Wages £	2,367	2,436	2,548	2,620	2,662	2,587	2,842	2,717	2,874	2,565
Materials "	2,287	2,416	2,491	2,988	2,593	3,021	3,004	3,487	3,734	2,371
Total[2] "	4,806	4,987	5,191	5,791	5,399	5,764	6,021	6,398	6,802	5,141
Per passenger train-mile d	1·76	1·82	1·88	2·10	1·94	2·16	2·18	2·33	2·47	1·90
Stock of carriages	312	313	314	339	339	345	345	347	347	347
Cost of wagon maintenance—										
Wages £	2,598	1,722	1,624	1,610	1,448	1,416	1,387	809	865	1,158
Materials "	3,377	2,667	2,656	2,557	3,321	2,630	3,119	2,393	2,144	2,205
Total[2] "	6,186	4,633	4,491	4,383	4,981	4,280	4,770	3,467	3,275	3,651
Per goods train-mile d	4·00	3·17	2·91	2·98	3·03	2·58	2·77	2·12	1·80	2·16
Stock of wagons	2,025	2,025	2,025	2,050	2,075	2,100	2,226	2,276	2,426	2,457

[1] Half salaries, &c., included in these totals.

[2] Salaries, &c., included in these totals.

TABLE XX.—PARTICULARS RELATING TO THE GREAT NORTHERN (IRELAND) RAILWAY.

—	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger . . .	1,013,956	983,492	1,013,324	988,580	1,022,403	1,001,139	1,032,806	1,009,516	1,045,817	1,034,786
„ goods	461,398	448,211	473,123	447,846	488,499	452,794	487,087	462,264	497,383	443,299
Total . . .	1,475,354	1,431,703	1,486,447	1,436,426	1,510,902	1,453,933	1,519,893	1,471,780	1,543,200	1,478,085
Cost of engine maintenance—										
Wages . . . . . . £	5,857	5,619	5,728	5,603	5,828	5,363	5,396	4,830	3,840	5,265
Materials . . . . . „	8,132	4,981	7,550	7,207	8,390	6,850	7,888	6,061	6,618	5,501
Total [1] . . . . . . „	14,619	11,290	13,939	13,572	14,855	12,983	14,001	10,588	10,972	11,620
Per train-mile . . . d	2·37	1·89	2·25	2·26	2·35	2·14	2·21	1·72	1·70	1·88
Cost of running expenses [1] £	28,559	27,741	29,226	28,387	32,452	33,574	37,649	37,369	39,064	37,205
Ditto per train-mile . . d	4·64	4·65	4·71	4·72	4·49	5·54	5·94	6·09	6·07	6·04
Stock of engines	137	137	137	137	137	137	137	137	137	137
Train-miles per engine . .	10,769	10,450	10,850	10,484	11,028	10,612	11,094	10,742	11,264	10,789
Cost of carriage maintenance—										
Wages . . . . . . £	2,707	2,606	2,650	2,868	2,667	2,707	2,588	2,787	2,555	2,564
Materials . . . . . „	4,649	4,684	4,727	4,624	4,340	5,206	4,076	4,714	3,207	4,225
Total [2] . . . . . . „	7,594	7,536	7,589	7,707	7,223	8,182	6,838	7,670	5,985	7,000
Per passenger train-mile d	1·79	1·83	1·79	1·87	1·69	1·94	1·58	1·82	1·37	1·63
Stock of carriages . . .	490	498	504	504	514	517	526	535	543	548
Cost of wagon maintenance—										
Wages . . . . . . £	3,108	3,265	3,134	3,097	3,264	3,152	3,219	3,098	3,526	3,033
Materials . . . . . „	4,319	4,923	4,702	4,367	4,471	4,955	4,741	4,919	4,480	4,549
Total [2] . . . . . . „	7,665	8,435	8,049	7,678	7,951	8,325	8,174	8,237	7,829	7,794
Per goods train-mile . d	3·98	4·51	4·08	4·11	3·90	4·41	4·02	4·28	3·77	4·21
Stock of wagons	3,409	3,425	3,459	3,482	3,506	3,524	3,552	3,582	3,608	3,630

[1] Half salaries, &c., and half repairs to shops and sheds, included in these totals.

[2] Salaries, &c., included in these totals.

TABLE XXI.—PARTICULARS RELATING TO THE BELFAST AND NORTHERN COUNTIES RAILWAY.

—	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger	369,525	340,953	374,276	357,291	418,401	390,066	431,163	380,842	471,909	428,562
„ goods	162,494	161,997	170,453	179,905	216,698	206,936	219,258	219,018	218,621	225,889
Total	532,019	502,950	544,729	537,196	635,099	597,002	650,421	599,860	690,530	654,451
Cost of engine maintenance—										
Wages £	1,761	1,814	1,893	2,012	2,583	2,192	2,457	2,750	2,747	2,849
Materials „	1,973	1,710	3,237	1,878	3,316	2,237	2,553	2,115	2,683	2,559
Total [1] „	3,858	3,653	5,367	4,033	6,047	4,593	5,172	5,038	5,613	5,549
Per train-mile d	1·74	1·74	2·36	1·80	2·28	1·84	1·90	2·01	1·95	2·03
Cost of running expenses [1] £	9,850	9,170	10,738	11,386	13,720	13,269	15,467	15,240	16,118	15,212
Ditto per train-mile d	4·44	4·37	4·73	5·10	5·18	5·33	5·70	6·09	5·60	5·57
Stock of engines	52	52	52	52	58	60	61	61	61	63
Train-miles per engine	10,231	9,672	10,475	10,331	10,950	9,950	10,662	9,833	11,320	10,388
Cost of carriage maintenance—										
Wages £	895	883	985	977	1,288	1,291	1,529	1,350	1,265	1,288
Materials „	996	1,134	1,150	1,601	1,903	2,064	2,201	2,224	2,398	1,941
Total [2] „	1,945	2,081	2,203	2,650	3,265	3,436	3,810	3,660	3,755	3,325
Per passenger train-mile d	1·26	1·46	1·41	1·78	1·87	2·11	2·12	2·30	1·90	1·86
Stock of carriages	217	217	217	219	234	234	240	252	264	276
Cost of wagon maintenance—										
Wages £	1,314	1,312	1,195	1,272	1,188	1,131	1,263	1,196	1,370	1,253
Materials „	1,556	1,475	1,577	1,669	1,529	1,427	2,000	1,857	2,252	2,175
Total [2] „	2,924	2,851	2,842	3,013	2,792	2,639	3,344	3,139	3,714	3,524
Per goods train-mile d	4·31	4·22	4·00	4·01	3·09	3·06	3·66	3·43	4·07	3·74
Stock of wagons	1,471	1,471	1,476	1,526	1,884	1,884	1,878	1,886	1,886	1,949

[1] Half salaries, &c., included in these totals.

[2] Salaries, &c., included in these totals.

TABLE XXII.—PARTICULARS RELATING TO THE GREAT SOUTHERN AND WESTERN RAILWAY OF IRELAND.

—	1887.	1888.		1889.		1890.		1891.		1892.
	December.	June.	December.	June.	December.	June.	December.	June.	December.	June.
Mileage—passenger	939,650	944.248	953,351	957,205	989,863	946,887	1,016,823	1,017,088	1,034.221	1,020,494
„ goods	587,462	575,472	585,424	597,351	619,819	598,157	674,379	660,503	698,895	652,398
Total	1,527,112	1,519,720	1,538,775	1,554,556	1,609,682	1,545,044	1,691,202	1,677,591	1,733,116	1,672,892
Cost of engine maintenance—										
Wages . . . £	9,317	9,173	8,796	8,943	9,061	8,215	8,910	8,829	8,997	9,003
Materials . . . „	8,162	8,054	8,235	9,318	8,666	9,790	8,521	8,863	10,009	8,965
Total[1] . . .	18,020	18,631	18,511	19,748	19,151	19,590	18,929	19,256	20,485	19,604
Per train-mile . . d	2·83	2·94	2 88	3·04	2·85	3·04	2·68	2·75	2·83	2·81
Cost of running expenses[1] £	31,592	32,457	33,153	32,398	39,811	40,739	46,076	46,512	44,077	41,850
Ditto per train-mile . . d	4·95	5·12	5·17	5·15	5·93	6·32	6·53	6·65	6·11	6·00
Stock of engines . . .	176	176	176	176	176	176	177	178	178	178
Train-miles per engine . .	8,676	8,635	8,743	8,832	9,146	8,778	9,555	9,424	9,736	9,398
Cost of carriage maintenance—										
Wages . . . £	3,467	3,691	3,465	3,3°0	3,457	3,184	3,382	2,957	3,254	3,234
Materials . . . „	4,533	5,854	5,010	5,222	5,423	5,292	5,295	4,867	5,045	4,501
Total[2] . . . „	8,137	9,686	8,621	8,751	9,033	8,643	8,843	7,989	8,465	7,901
Per passenger train-mile d	2·07	2·46	2·17	2·19	2·18	2·19	2·08	1·88	1·95	1·85
Stock of carriages . . .	525	525	525	525	525	525	525	530	532	535
Cost of wagon maintenance—										
Wages . . . £	3,626	3,598	3,559	3,402	3,418	3,211	3,414	3,285	3,652	3,480
Materials . . . „	6,920	5,955	7,659	6,688	6,441	6,026	7,326	6,499	6,992	7,152
Total[2] . . . „	10,683	9,693	11,363	10,238	10,011	9,404	10,906	9,950	10,810	10,798
Per goods train-mile . d	4·36	4·04	4·65	4·11	3·87	3·77	3·88	3·61	3·71	3·97
Stock of wagons . . .	3,521	3,521	3,521	3,521	3,521	3,571	3,701	3,821	3,921	3,962

[1] Half salaries, &c., and half repairs to shops, sheds, &c., included in these totals.

[2] Salaries, &c., included in these totals.

APPENDIX III.

TABLE XXIII.—PARTICULARS OF ENGINE RENEWALS FIVE YEARS ENDING JUNE, 1892.

Name of Company.	Average Stock.	Average renewed annually.	Percentage renewed annually.
Midland Railway	1,897	126·8	6·6
Great Western Railway	1,624	45·6	2·8
,, Eastern ,, ...	800	28·2	3·4
Caledonian ,, ...	690	24·6	3·6
North British ,, ...	628	28·6	4·4
London, Brighton & South Coast Railway	410	9·2	2·2
Glasgow and South Western Railway .	298	8·0	2·6
		Average .	. 3·6

TABLE XXIV.—PARTICULARS OF CARRIAGE RENEWALS FIVE YEARS ENDING JUNE, 1892.

Name of Company.	Average Stock.	Average renewed annually.	Percentage renewed annually.
Belfast and Northern Counties Railway, Ireland	236	8·0	3·4
North British Railway, Scotland . . .	2,056	58·8	2·8
Caledonian ,, ,, ...	1,694	63·4	3·6
Glasgow and South-Western Railway, Scotland	980	31·0	3·2
London and South-Western Railway .	3,064	47·0	1·52
Great Eastern Railway	3,431	117·6	3·4
London, Brighton & South Coast Railway	2,817	70·4	2·4
London, Chatham and Dover Railway .	1,060	25·8	2·4
South-Eastern Railway	2,128	21·2	1·0
Midland Railway [1]	4,024	68·0	1·64
		Average .	. 2·53

TABLE XXV.—PARTICULARS OF WAGON RENEWALS FIVE YEARS ENDING JUNE, 1892.

Name of Company.	Average Stock.	Average renewed annually.	Percentage renewed annually.
Belfast and Northern Counties Railway, Ireland	1,731·0	17·2	1·0
North British Railway, Scotland . . .	40,618·0	1,237·6	3·0
Caledonian ,, ,, ...	46,800·0	1,277·6	2·6
Glasgow and South-Western Railway, Scotland	12,630·0	640·6	5·0
London and South-Western Railway. .	8,934·0	282·8	3·0
Great Eastern Railway	15,311·0	307·6	2·0
London, Brighton & South Coast Railway	7,133·0	322·2	4·4
London, Chatham and Dover Railway .	2,045·0	24·0	1·2
South-Eastern Railway	5,128·0	125·2	2·4
Midland Railway	95,214·5	6,102·4	6·4
		Average .	. 3·1

[1] Nearly the whole of the Midland carriage stock was rebuilt during the nine years preceding 1887.

(*Paper No. 2869.*)

"Experiments on Centrifugal Fans."

By Bryan Donkin, M. Inst. C.E.

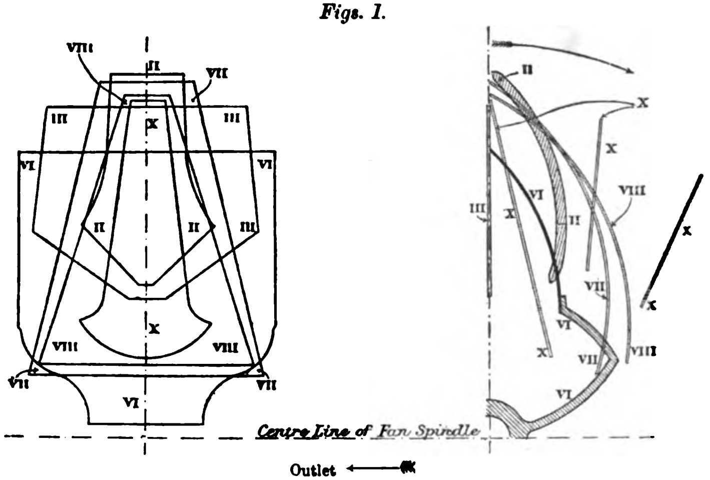
No systematic record seems hitherto to have been available of experiments on the smaller classes of centrifugal fan used for cupolas, smiths' fires, &c. Some have been made on a few types, but data are not given as to the power absorbed in relation to the pressure and quantity of air delivered. Hence, proper comparisons with a view to determine the relative values of fans of different kinds cannot be made. The Author has conducted experiments on fans of several types, varying and measuring the quantities and pressures of air passed, and ascertaining the power absorbed. In this way he has determined the pressure, volumetric and mechanical efficiencies, important points upon which manufacturers generally give little information. The trials were made at Bermondsey, during 1893–4.

A fan may be described as an aero-dynamic machine for delivering a certain quantity of air at a required pressure. The best fan will give this result at the minimum speed, when absorbing the minimum power, with the least noise, and in the least space. The pressure, volumetric and mechanical efficiencies should be as high as possible. In other words, a fan is a transformer of mechanical power into potential energy of air under pressure. Through a fan of known dimensions and type a certain quantity of air was allowed to pass, and the resulting pressure and indicated HP. absorbed were observed. With the same fan, other conditions remaining constant, the quantity of air delivered was found to vary with the speed, an increase of 20 per cent. in the latter corresponding with an increase of 20 per cent. in the quantity of air passed, within the limits of the experiments. When the speed was maintained constant and the quantity of air passing through the fan was varied, the pressure and the power absorbed were determined, and when the pressure was constant, the quantity of air, the speed and the power were obtained.

In each set of experiments upon a given type of fan, the quantity of air passing was varied, and a corresponding change in the pressure was produced. This was easily and quickly effected by

throttling the flow in the delivery-pipe at some distance from the fan, and allowing the air to pass successively in each experiment through wove-wire of 3, 8, 30 and 50 meshes to an inch. The "equivalent orifice"[1] was also varied by the insertion of one to four pieces of perforated zinc superposed. The wove-wire of 3 and 8 meshes to an inch gave respectively by calculation an effective area of 80 per cent. and 56 per cent. of the area of the pipe. One piece of perforated zinc gave an area of 40 per cent. Experiments under these several conditions, as well as with no baffle, were made upon each fan, the end of the delivery-pipe being free to the atmosphere in all cases. This end was in a final experiment completely stopped, and the air,

Figs. 1.



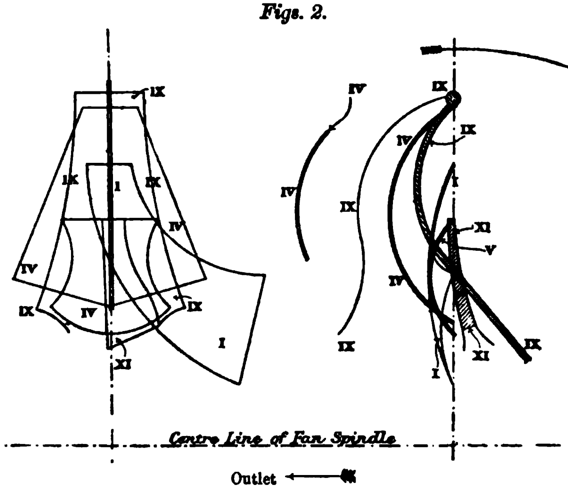
VANES CONVEX TO THE OUTLET.

instead of passing through, was churned up inside the fan. The I.HP. was taken in each case, as well as the pressure of the

[1] The expression "equivalent orifice," employed by Mr. D. Murgue in his book on "The Theories and Practice of Centrifugal Ventilating Machines," is used to denote the area of the circular orifice that would discharge the quantity of air with the head given, taking the practical coefficient of 0·65 in the formula given in Appendix II. Professor Rateau employs the expression "ouverture," which differs from "equivalent orifice" only by a constant factor near to unity. Mr. Guibal, for large mining fans, uses the expression "temperament," which represents the same value multiplied by a constant. The "ouverture," "equivalent orifice," or "temperament" are all diminished when, during a series of experiments, increasing obstructions are offered to the passage of the air by the insertion of baffle-plates, wove-wire, or pieces of perforated zinc in the discharge-pipe.—B.D.

air and the speed of the fan. About ten experiments were made on each fan, each occupying about fifteen minutes after all conditions had become constant; and as a similar series of experiments was made upon each, with the same pipe and apparatus, the results are comparable. Eleven different types of fan were tested, of diameters varying between 16 inches and 2 feet 1½ inch. The number and shape of the vanes differed considerably, as will be seen in *Figs. 1* and *2*. Each fan was driven by a strap from the same steam-engine, which was indicated to give the power absorbed. The I.HP. required to drive the engine at different speeds was accurately known, and was in each case deducted from the total I.HP.

Figs. 2.



VANES CONCAVE TO THE OUTLET.

A large quantity of air is required at low pressure in some cases, and in others, a small quantity at high pressure. The volume of air passing at the maximum pressure with a given speed of the fan and equivalent orifice was determined in the experiments. The formulas in Appendix II show the methods of calculating the volumetric, pressure, and mechanical efficiencies. The number of vanes of each fan, together with their shape and direction of curvature, are given in Table II of Appendix I. The casing in which the vanes revolved differed considerably in shape, but was always of cast-iron. The vanes revolved in some cases with the concave, in some with the convex, and in others with the flat side, to the outlet. They were set some-

times radially and sometimes inclined to the centre of the shaft. The fan was in some cases driven with the blades revolving in the opposite direction to that indicated by the makers (other conditions being unchanged as to baffle-plates, &c.), and an increase in the quantity of air delivered found to result. In two instances the spindle was driven alone with the blades removed, in order to determine the power absorbed by the shaft revolving in its bearings at a certain speed. With one or two fans several holes were drilled in the outer casing, and a small Pitot tube was introduced, to ascertain the direction, the pressure and the velocity of the currents of air leaving the blades, striking against the casing and passing round to the outlet. A complete Paper on the subject of mining and small fans has been published by Professor Rateau, Ingénieur des Mines, of St. Etienne, France,[1] whose assistance the Author desires to acknowledge, as well as that of Professor Boulvin of Ghent. The latter gentleman has kindly checked many of the calculations. Various experiments are quoted in Professor Rateau's Paper, and his theory is given with many applications. On the difficult subject of the correct measurement of the flow of air in pipes few tests have been published. Some of the best and most recent known to the Author were made at Breslau, by the Prussian Mining Commission, and were reported on by Mr. Althans.[2]

A drawing of each fan is given in Figs. 3, Plate 2. The maximum efficiency or the best experiment on each is given in Table II, Appendix I, and the volumetric, pressure and mechanical efficiencies are represented graphically in Figs. 5, 6, and 7, Plate 2. As regards possible experimental errors, the speeds, pressures and quantities of air are probably correct to within 3 or 4 per cent. The Author conducted the experiments with two trained assistants, and the observations were not recorded until all conditions were constant. Table III, Appendix I, gives the results of the experiments on the different fans with maximum and minimum equivalent orifices, together with particulars as to speed, &c., observed in the tests.

Experimental Apparatus.—A conical piece of pipe, Y X, Figs. 4, Plate 2, fitting the outlet of each fan, was bolted, as shown, to the fan under test on one side, and to a wrought-iron pipe $14\frac{1}{32}$ inches in

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[1] "Considerations sur les Turbo-Machines et Ventilateurs." M. Rateau.

[2] "Anlagen zum Haupt-Berichte der Preuss. Schlagwetter Commission," and Appendix III of this Paper. See also Minutes of Proceedings Inst. C.E., vol. cxi. p. 345.

diameter on the other. This latter was used for all the experiments. Each fan was driven from a small engine by a strap from a rigger fixed on the crank-shaft. To indicate the speeds of the fan and engine, two counters were so arranged that they could be started and stopped simultaneously, one being driven from the end of the fan spindle, and the other from that of the engine crank-shaft. Two assistants started the counters by signal at the same instant, and at the end of the experiment they were similarly thrown out of gear. By this means, the speeds and slip of the strap were obtained. At A and B, two pipes of $\frac{1}{4}$ inch diameter, were fixed to the air-pipe Y Z, and to these were attached two U water-gauges, by which the static pressures of air were observed. The dynamic pressures were obtained by means of a dial gauge of special design. The circular pieces of wove-wire or perforated zinc were fixed inside the pipe at C, causing the air to be uniformly baffled, diminishing the quantity passing through the fan, but increasing the pressures as the areas were successively reduced. These pieces of wire or zinc were changed for each experiment. The free end of the pipe at Z delivered the air from the fan into the atmosphere. The pressures of air, the speeds of the engine and fan, and the I.HP. were thus determined for each experiment. The quantity of air was measured in each of the ten experiments on every fan. The Pitot tube system was adopted for the measurement of the air as being quite as correct as, and more convenient than, an anemometer. Had the latter instrument been used, its particular position in the pipe must have been considered, as the speed of the air varied greatly, from a maximum at the centre to a minimum at the circumference. An important point was to determine the mean speed of the air in the pipe Y Z. The Breslau experiments showed that anemometers give too high results when calibrated in the usual way in a circular path. The Author made some experiments with a $2\frac{3}{4}$-inch diameter anemometer, and, allowing for the error of calibration as determined by experiments, found them to agree practically with the Pitot tube method. The speeds of the air on issuing from the pipe into the atmosphere were measured in each experiment at Z in the following way:—A carefully-made brass Pitot tube $\frac{1}{4}$ inch in internal diameter was held in the hand with its open end facing the currents of air at Z. The other end was connected by an india-rubber pipe to a special dial water-gauge, Figs. 4, Plate 2, on which the dynamic pressures due to varying velocities of air, at different positions in the pipe, were indicated. On this gauge a deflection of 33 millimetres represented a water-pressure of 1 millimetre.

At the free end of the pipe at Z, a template of wire was fixed, dividing it into eight equal areas. At the centre of gravity of each of these areas the Pitot tube was supported by the wire template. The mean of these eight readings in each experiment was taken as the average pressure in millimetres of water. The dynamic air-pressure was also taken at a distance of two-thirds of the radius from the centre of the pipe. The Breslau experiments showed that this particular position gave the mean dynamic air-pressure in the pipe due to the mean velocity, a result which was confirmed by the Author's tests. The mean dynamic pressure at Z having been thus obtained, the mean velocity of the air was deduced from the formula given, which was nearly the same as that recommended by Mr. Althans. The mean velocity having been determined, the quantity of air in cubic feet per second was obtained by multiplying the velocity by the area of the pipe. The latter was gauged inside the end of the pipe Z, allowance being made for the wire template. The temperature of the air at Z was noted in each experiment with a wet and dry bulb thermometer, and the barometric pressure was also observed.

TYPES OF FAN (*Figs. 1 and 2* and Figs. 3, Plate 2).

Fan No. I.—This fan was made with twenty specially-shaped wrought-iron vanes curved in two directions, and revolving with the concave side to the outlet. The casing, of volute form, gradually increased in cross-sectional area towards the outlet. There was only one inlet for air, of special bell-mouthed form. The driving shaft was fixed in the centre of the inlet, with a cone on its end to guide the air into the revolving blades, and there was no bearing or obstruction to prevent the air from entering freely. The two brass bearings for the shaft, one with three thrust collars and one plain, measured 1⅜ inch in diameter by 5¼ inches long. This fan worked very quietly. In this case details of the ten experiments are given, in Table I, Appendix I. Little attention was paid to ensuring any particular speed in each experiment, as it was found in the fans tested that, all other conditions being the same, the quantity of air delivered was proportional to the speed. The three efficiencies of this fan are all high. Two special experiments were made with a sheet of perforated zinc in the pipe, one with the vanes varnished and covered with coal-dust, to represent dirty vanes in a coal mine, and the other with the vanes clean and bright. Corrected for speed, the results of the comparison showed that 10½ per cent. more air was delivered by the clean vanes, but the

mechanical efficiency was about the same. The pressure efficiency was 11 per cent., and the volumetric efficiency 6 per cent., higher with the clean than with the dirty vanes. Two experiments were made, one with the large bell-mouthed inlet fixed in place as designed, and one with it removed. Corrected for speed, the result showed that 31 per cent. more air was passed when the inlet was used, and the mechanical efficiency was 9 per cent. higher. The pressure efficiency was 33 per cent. and the volumetric efficiency 15 per cent. higher. This proves the advantage of admitting the air without shock and in the right direction. In Figs. 4[a], Plate 2, is given the variation of the pressures at the end of the pipe, taken with a Pitot tube connected with the dial water-gauge, in an experiment on this fan. The end of the pipe at Z was divided into eight equal areas, and the pressure was taken in each. In this experiment, with two sheets of perforated zinc in the pipe, the mean of the eight readings gave a velocity of 1,888 feet per minute (see Table I). The velocity, taken from the mean of the pressures at points two-thirds of the radius distant from the centre, was 1,896 feet per minute. The velocity obtained from the pressure at the centre of the pipe taken at the same time was 1,929 feet per minute. In Fig. 8, Plate 2, are plotted the results of all the experiments with this fan on the basis of equivalent orifices.

Fan No. II.—This fan had twelve short curved vanes cast in one piece, revolving concave to the outlet, but some experiments were made with the vanes running in the contrary direction, to ascertain the effect on the pressures and quantities of air. The outer cast-iron casing was of volute form gradually increasing in area towards the outlet. It was provided with two central air-inlets. The shaft was placed centrally with the inlet, but eccentric to the casing, and the bearings were near the inlets. Ten experiments were made with the vanes running concave to the outlet. The three efficiencies obtained were fairly good. Two experiments were also made with the vanes reversed and revolving convex to the outlet. The increase in the quantity of air delivered due to the vanes revolving concave to the outlet was found to be 11 per cent. The mechanical efficiency was 5 per cent. less in the latter case, but in pressure efficiency a gain of 5½ per cent., and in volumetric efficiency a gain of 2½ per cent., was effected. An experiment was also made with the spindle running alone in its bearings, the vanes being removed. The I.HP. absorbed was 0·55 at a speed of 1,230 revolutions per minute. The two bearings measured 1⅜ inch in diameter by 5¼ inches long,

and were lubricated as usual. The air-pressure at the highest part of the fan was also observed, a hole being there drilled for a U-gauge. It was found to be $4\frac{1}{8}$ inches of water, when the gauge at A showed $4\frac{1}{2}$ inches. The fan was running at a speed of 1,348 revolutions per minute, with vanes convex to the outlet, and three sheets of zinc in the pipe. The quantity of air passing was 1,076 cubic feet per minute.

Fan No. III.—This fan was one of the simplest tested, and had only six short, straight, radial, wrought-iron vanes with two inlets for air, the shaft being central with the inlets. The cast-iron casing was eccentric to the shaft, so that the cross-sectional area gradually increased towards the outlet. The two bearings, of white metal, measured $1\frac{1}{4}$ inch in diameter by $5\frac{1}{2}$ inches in length, and were well lubricated, the fan working quietly. Ten experiments were made with the various baffles. It will be seen that the three efficiencies obtained in the best experiment occupy relatively a good position.

Fan No. IV.—This fan was of a special duplex type, the air passing from an outer into an inner casing, and from thence to the outlet; the vanes were mounted on a centre-plate of wrought-iron, so that one-half of them were in the outer and the other half in the inner casing. There were eight large and eight small vanes on each side of the centre-plate, revolving concave to the outlet. In this case there were three bearings for the spindle, $1\frac{1}{8}$ inch in diameter by 5 inches long, of white metal. It was not possible to make experiments with the direction of the vanes reversed. The usual ten experiments were made, the area of the pipe being reduced in successive experiments.

Fan No. V.—This fan was made with twenty-four short curved wrought-iron vanes intended to revolve with the concave side towards the outlet. It had two inlets, small and bell-mouthed, to direct the entering air. In addition, there were cones mounted on the shaft with the same object. The outer casing was of cast-iron of volute form, the area increasing gradually towards the outlet. The two bearings, arranged to allow for any deflection of the shaft, were $1\frac{1}{16}$ inch in diameter by $4\frac{5}{8}$ inches long, and were placed well away from the inlets. Fourteen experiments were made with different baffles in the air-pipe, and with the vanes revolving concave to the outlet. It will be seen that the three efficiencies in the best experiment are all relatively high. One experiment was made with the two external bell-mouthed inlets removed, the directions of the vanes remaining the same, to test their effect on the quantity of air, &c. Corrected

for speed there was a gain of 3½ per cent. in the quantity of air delivered, due to these inlets; there was also a gain of 4¼ per cent. in mechanical efficiency, and 5¾ per cent. in pressure efficiency.

Fan No. VI.—The peculiarity of this fan was that its six vanes had not one curvature throughout their length, but at about the middle they were set back and then continued to the full radius, as shown in Figs. 3, Plate 2. They were intended by the maker to revolve convex to the outlet. There were two inlets, the shaft being placed centrally with them, but eccentric to the outer casing. Two cast-iron bearings were provided, about 1½ inch in diameter by 8 inches long, but these were too near the inlets to give the best effect. This fan worked with a humming noise. Eleven experiments were made with the vanes revolving convex to the outlet. The three efficiencies are not high, and lower than in many of the other fans. An experiment was also made with vanes revolving concave to the outlet, and when corrected for speed there was a gain of 25 per cent. The mechanical efficiency was about the same, the pressure efficiency 19 per cent., and the volumetric efficiency 10 per cent. higher with the vanes working thus.

Fan No. VII.—This type of fan has been used in England for many years. It has six wrought-iron vanes revolving convex to the outlet. The vanes are considerably curved, and longer than in the other types. There are two inlets for air, but the bearings are placed very near them, an arrangement which prevents the free entrance of the air. The spindle, 1⅝ inch in diameter, revolved, in bearings 7 inches long, centrally with the inlets and the cast-iron outer casing. The air-passage between the ends of the revolving vanes and the casing was not increased in area towards the outlet, as in the other fans. Ten experiments were made, with the vanes running as intended by the maker, convex to the outlet.

Fan No. VIII.—This fan was somewhat similar to the last-mentioned, and had six wrought-iron vanes of considerable curvature, intended to run convex to the outlet. There were two inlets for air, and the centre of the shaft was placed centrally with these, but slightly eccentric to the outer casing. The spindle was supported in two cast-iron bearings 1½ inch in diameter and 7 inches long. The bearings were too close to the inlets. Ten experiments were made, with the usual wire and zinc baffles, and with vanes running convex to the outlet. The efficiencies were somewhat low, as may be seen from the plotted results, Fig. 9, Plate 2. Other experiments were made with the vanes running

concave to the outlet, to ascertain the effect on the quantity of air delivered, the power, &c. Corrected for speed, the quantity of air delivered was $5\frac{1}{2}$ per cent. greater, the mechanical efficiency 11 per cent. less, the pressure efficiency 7 per cent. higher, and the volumetric efficiency about the same as with the vanes running convex to the outlet.

Tests were made to ascertain the pressure between the ends of the revolving blades and the casing. A hole was drilled at the highest part of the fan for a U-gauge. The blades were running at 1,561 revolutions per minute, convex to the outlet, with four sheets of zinc in the pipe. The pressure was found to be equal to a head of $4\frac{1}{16}$ inches of water, corresponding with a velocity of air of 8,800 feet per minute, while the pressure at A was $5\frac{5}{8}$ inches, equal to a velocity of 9,420 feet per minute. Other experiments proved that the static head inside the casing increased gradually round the circumference from $4\frac{7}{8}$ inches of water just above the outlet to $5\frac{5}{8}$ inches near the outlet. The quantity of air passing at the same time was 675 cubic feet per minute.

Fan No. IX.—Fans of this type have been used in considerable numbers on the Continent. Four vanes, an unusually small number, of thin cast-iron, are provided, and are intended to revolve concave to the outlet. There were two inlets for the air placed centrally to the shaft, and also to the outer casing which was of cast-iron. The two bearings, with white-metal linings, were 1 inch in diameter by 5 inches long. These were situated too near the inlets to give the best results. This fan was always noisy, particularly when running with small equivalent orifices. Ten experiments were made with the vanes running concave to the outlet, but none with the direction of the vanes reversed.

Fan No. X.—This fan was designed especially to give a great pressure of air, and not with a view of delivering a large quantity. There were in all eighteen vanes, six of which were whole vanes, and twelve half-vanes interposed. They were all cast in one piece and straight, but not set radially to the centre. There were two inlets centrally with the shaft, coned to guide the entering air. The boss of the revolving part was also curved to assist the entrance of the air. The outer casing was of cast-iron, centrally with the shaft and of rectangular section, gradually increasing in area to the outlet. The shaft revolved in two bearings of white metal $1\frac{3}{16}$ inch in diameter and 6 inches long, placed well away from the air-inlets. Thirteen experiments were made with a different number of baffles. It will be seen that this fan gave

fairly good results when compared with others, but it must be remembered that it was designed for pressure. The diameter of the pulley was 3 inches. One experiment was made with the vanes running in a contrary direction to that shown in the drawing, Figs. 3, Plate 2. The results corrected for speed showed that the quantity of air delivered was 31 per cent. more, the mechanical efficiency 4 per cent. less, the pressure efficiency $1\frac{1}{2}$ per cent. less, and the volumetric efficiency 3 per cent. higher. The fan worked quietly. An attempt was made to obtain the pressure and velocity of the air inside the casing between it and the revolving blades when running at 1,758 revolutions per minute, and with three sheets of perforated zinc superposed in the pipe. A Pitot tube was held against the current, close to the edge of the revolving blades, and also as near the inside of the casing as possible. The pressure was found to be higher when close to the vanes. At D, No. X, Figs. 3, the dynamic pressure, when the tube was held close up to the vanes, was $11\frac{1}{8}$ inches of water, corresponding with a velocity of 13,080 feet per minute, and with the tube as near the outer casing as possible the pressure was $9\frac{15}{16}$ inches of water, or 12,500 feet per minute. At E, the opposite point on the circumference, the dynamic pressure, when the tube was held close to the vanes, was $11\frac{7}{8}$ inches head of water, or 13,690 feet per minute, and with the tube as near the outer casing as possible $11\frac{1}{2}$ inches, or 13,480 feet per minute. Thus it will be seen that the velocity of the air increased round the inside of the casing with the direction of rotation, for the same speed of fan. The static pressure at A in the experimental apparatus, Figs. 4, at the same time was $9\frac{1}{8}$ inches of water, and the quantity of air delivered was 1,291 cubic feet per minute.

Fan No. XI.—This fan was made with blades fixed on one side only of a disk, having ten cast-iron slightly curved thick vanes revolving concave to the outlet. It had only one special inlet, which constituted its peculiarity. The air was allowed to enter, not parallel with the fan shaft, as in all the other fans tested, but at right-angles to it. In this way a rotary motion was given to the air before it came in contact with the revolving vanes. The object of the arrangement was to minimise friction. The experiments, however, show that it was of little use. The outer casing was of cast-iron of volute form. There were two cast-iron bearings, $1\frac{1}{4}$ inch diameter, about 8 inches long. Nine experiments were made with the usual baffles, and one experiment with the vanes removed and the spindle running alone. At a speed of 2,100 revolutions per minute, the I.HP. absorbed was

0·43. It will be seen that the three efficiencies occupy a low position in plotted results.

General Results.

A few practical conclusions from these tests may be mentioned. It seems that few English and Continental manufacturers make experiments to ascertain the quantity of air delivered, the pressure and the power absorbed. Sufficient attention is often not given to the admission of air to the centre of the fan to reduce friction. The number and shape of the vanes and their direction of rotation seem often to have been guessed at and not deduced from experimental research, which is still needed to decide the latter question for a given speed, quantity and pressure of air. Between twenty and twenty-five vanes give the best results. The shape of the blades, their number and the space between them and the outer casing, exercise a considerable influence on the various efficiencies. The final inclination, or angle, of the vanes at their circumference has more effect on the pressure of the air, and less on the mechanical and volumetric efficiencies. The revolving portion of the fan should always be accurately balanced. The friction of the spindle in its bearings deserves more attention than it has hitherto received, and continuous lubrication at high speeds should increase the mechanical efficiency. Allowance should also be made for the deflection of the spindle. The pulley should not be too small or too narrow, so as to diminish the slip of the strap. The friction of the air inside the casing is often excessive, and care should be taken to allow its entrance and passage through the vanes, and out of the fan, with a minimum of skin friction. Changes of direction and shocks which reduce the losses of head with the high velocities of air should be avoided as much as possible.

The Author desires to express his indebtedness to those who have lent him fans for the purposes of these tests. Much good experimental work has been accomplished with large mining-fans, particularly in Belgium, France and Germany; but still more might with advantage be undertaken in this important branch of aero-dynamics. The employment of centrifugal fans both at sea and on land for artificial draught is extensive and increasing, but few experiments on such machines are available.

The Paper is accompanied by tracings, from which Plate 2 and the *Figs.* in the text have been prepared.

APPENDIXES.

APPENDIX I.

TABLE I.—EXPERIMENTS ON FAN NO. 1. TWENTY WROUGHT-IRON VANES RUNNING CONCAVE TO THE OUTLET. ONE INLET ONLY.

Revolutions of Fan per Minute.	Slip of Strap per Cent.	Static Pressure at A, in Inches of Water.	Dynamic Pressure at B, in Inches of Water.	Velocity of the Air at Z, in Feet per Minute.	Quantity of Air Delivered in Cubic Feet per Minute.	Temperature of Air at the end of the Pipe by Thermometers with Wet and Dry Bulbs, in Degrees Fahr.	Barometric Pressure, in Inches of Mercury.	Velocity of the Circumference of the Vanes, in Feet per Second.	HP. absorbed by Fan deducting I.HP. of Engine at the Speed.	Theoretical HP. or Calculated Work.	Mechanical Efficiency, per Cent.	Pressure Efficiency, per Cent.	Volumetric Efficiency, per Cent.	"Ouverture," Square Feet.	"Equivalent Orifice," in Square Feet.	Conditions—Baffles used.
847	4·8	$\frac{3}{4}$ vac	$\frac{5}{8}$	3,341	3,560	61 wet, 76 dry	29·8	72·6	2·98	0·36	12·0	26·9	121·3	1·57	1·71	Free discharge.
857	4·6	$\frac{1}{2}$ vac	$\frac{13}{16}$	3,319	3,536	61 wet, 75 dry	30·2	73·6	2·67	0·46	17·1	33·6	119·0	1·39	1·52	One piece of 3-hole per inch wove-wire.
887	3·4	$\frac{1}{8}$ vac	$1\frac{1}{8}$	3,100	3,303	62 wet, $76\frac{1}{2}$ dry	30·2	76·1	2·73	0·58	21·3	42·8	107·5	1·11	1·20	One piece of 8-hole per inch wove-wire.
1,032	3·0	$1\frac{1}{8}$ pres	$2\frac{1}{8}$	3,186	3,395	53 wet, 62 dry	30·2	88·6	3·37	1·14	33·9	60·4	94·9	0·82	0·89	One piece of 30-hole per inch wove-wire.
1,173	5·0	$2\frac{1}{2}$	$3\frac{1}{2}$	2,875	3,064	64 wet, 76 dry	30·2	100·7	3·63	1·71	47·0	77·4	75·4	0·58	0·63	One piece of 54-hole per inch wove-wire.
1,291	3·7	$3\frac{7}{8}$	$4\frac{3}{4}$	2,534	2,700	44 wet, 54 dry	30·2	110·8	3·44	2·04	59·4	87·0	60·4	0·43	0·47	One sheet of perforated zinc — best experiment.
1,485	2·7	$5\frac{5}{8}$	6	1,888	2,012	63 wet, 78 dry	30·1	127·4	3·22	1·93	59·9	83·2	39·1	0·29	0·31	Two sheets of perforated zinc superposed.
1,553	2·7	$5\frac{3}{4}$	$5\frac{7}{8}$	1,417	1,510	54 wet, 65 dry	30·2	133·3	2·33	1·41	60·6	74·4	28·1	0·22	0·24	Three sheets of perforated zinc superposed.
1,525	1·3	$5\frac{1}{4}$	$5\frac{1}{2}$	726	773	46 wet, 52 dry	30·2	130·9	1·36	0·68	49·9	72·3	14·6	0·12	0·13	Four sheets of perforated zinc superposed.
1,527	5·0	$3\frac{13}{16}$	$3\frac{7}{8}$	0	0	0	30·1	131·1	1·41	0	0	50·0	0	0	0	Entirely blocked.

Radius of vanes 9·8 inches.

Area of the end of the pipe at Z less that of the wires, 1·066 square foot.

TABLE II.—SUMMARY OF THE BEST EXPERIMENT ON EACH OF THE ELEVEN TYPES OF FAN.

Number of Fan.	Type of Fan. — C.I. indicates Cast Iron W.I. indicates Wrought Iron.	Diameter over Vanes, in Inches.	Revolutions of Fan per Minute.	Static Pressure at Outlet of Fan A, Inches of Water.	Dynamic Pressure before Baffle B, Inches of Water.	Quantity of Air Delivered, in Cubic Feet per Minute.	I.HP. of Fan only.	Theoretical HP.	Mechanical Efficiency, Per Cent.	Pressure Efficiency, Per Cent.	Volumetric Efficiency, Per Cent.	Equivalent Orifice, Square Foot.	Conditions and Direction of Vanes to the Outlet.	Temperature of Air at end of Pipe, Thermometer in Water and Thermometer Dry, ° F.	Barometric Pressure in Inches of Mercury.
I	Twenty vanes, W.I., $1\frac{1}{2}$ inch wide at tip	$19\frac{3}{8}$	1,291	$8\frac{7}{8}$	$4\frac{3}{4}$	2,700	3·44	2·04	59·40	87·00	60·38	0·44	One sheet perforated zinc. Concave . .	44 wet, 54 dry	30·20
II	Twelve vanes, C.I., $2\frac{1}{2}$ inches wide at tip .	$25\frac{1}{8}$	1,854	$4\frac{1}{2}$	$4\frac{7}{8}$	1,905	3·81	1·47	44·49	48·68	18·65	0·33	Two sheets perforated zinc. Concave . .	75 wet, $77\frac{1}{2}$ dry	30·08
III	Six vanes, W.I., 7 inches wide at tip .	$23\frac{1}{4}$	1,248	$4\frac{1}{4}$	$4\frac{7}{16}$	1,657	1·93	1·18	60·92	63·20	23·34	0·30	Two sheets perforated zinc, straight. Radial	74 wet, $82\frac{1}{2}$ dry	30·36
IV	Eight vanes, W.I., and eight half vanes $4\frac{1}{8}$ inches wide at tip .	$28\frac{3}{8}$	1,014	$4\frac{9}{16}$	$5\frac{9}{16}$	1,261	3·16	1·05	33·13	52·65	20·75	0·21	Three sheets perforated zinc. Concave . .	55 wet, 68 dry	29·8
V	Twenty-four vanes, W.I., $3\frac{1}{2}$ inches wide at tip	$15\frac{3}{4}$	1,500	$8\frac{3}{8}$	$8\frac{11}{16}$	2,286	2·40	1·35	56·35	79·80	85·90	0·45	One sheet perforated zinc. Concave . .	88 wet, 91 dry	30·28
VI	Six vanes, W.I. . .	20	1,589	$8\frac{7}{8}$	$4\frac{1}{4}$	1,636	2·39	1·11	46·59	50·49	28·33	0·30	Two sheets perforated zinc. Convex . .	69 wet, 74 dry	29·7
VII	Six vanes, W.I., $3\frac{1}{4}$ inches wide at tip .	$24\frac{13}{16}$	1,855	$8\frac{7}{16}$	$8\frac{3}{4}$	1,526	2·47	0·91	36·95	39·02	15·93	0·30	Two sheets perforated zinc. Convex . .	61 wet, 69 dry	30·2
VIII	Six vanes, W.I., $1\frac{5}{8}$ inch wide at tip .	24	1,352	..	$8\frac{9}{16}$	1,163	1·66	0·66	39·57	39·59	13·82	0·24	Three sheets perforated zinc. Convex . .	56 wet, 61 dry	30·5
IX	Four vanes, C.I., $2\frac{1}{2}$ inches wide at tip .	$24\frac{5}{8}$	1,669	5	$5\frac{11}{16}$	1,074	2·11	0·97	46·10	38·88	9·48	0·16	Four sheets perforated zinc. Concave . .	55 wet, 63 dry	30·34
X	Eighteen vanes, twelve small and six large, $1\frac{3}{16}$ inch wide at tip	$28\frac{5}{8}$	1,747	$9\frac{1}{8}$	$8\frac{7}{8}$	1,280	3·22	1·82	56·57	59·25	12·22	0·17	Three sheets perforated zinc. Straight . .	57 wet, 61 dry	30·00
XI	Ten vanes, C.I., $\frac{3}{4}$ inch wide at tip . . .	$15\frac{3}{4}$	2,097	$1\frac{5}{16}$	$1\frac{5}{16}$	913	0·66	0·19	29·34	14·31	25·17	0·31	Two sheets perforated zinc. Concave . .	57 wet, 63 dry	30·52

TABLE III.—VARIATIONS BETWEEN THE RESULTS OF EXPERIMENTS WITH MAXIMUM AND MINIMUM EQUIVALENT ORIFICES ON EACH FAN.

No. of Fan.	Kind of Baffle in Pipe.	Revs. per Min.	Max. and Min. Equivalent Orifice.	Static Pressure at A.	Dynamic Pressure at B.	Velocity of air at end of pipe.	Quantity of air delivered.	Slip of Strap.	Efficiencies. Mechanical	Efficiencies. Pressure	Efficiencies. Volumetric
			Sq. feet.	Inches of Water.	Inches of Water.	Feet per Minute.	Cubic Feet per Minute.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
I	3-hole wire . .	857	1·52	0·50 vacuum	0·7 water	3,319	3,536	1·2	17·0	34·0	119·0
	4 sheets of zinc .	1,525	0·13	5·75 press.	6·0 "	726	773	5·0	50·0	72·0	15·0
II	3-hole wire . .	876	1·30	0·30 "	1·2 "	3,523	3,755	4·4	25·0	29·0	57·0
	4 sheets of zinc .	1,499	0·13	5·75 "	6·0 "	1,063	1,134	2·8	45·0	49·0	10·0
III	3-hole wire . .	980	1·43	0·16 "	1·0 "	3,827	4,077	5·5	32·0	27·0	73·0
	4 sheets of zinc .	1,088	0·17	5·10 "	5·2 "	795	847	0·5	61·0	68·0	14·0
IV	3-hole wire . .	706	1·44	1·00 vacuum	0·2 "	1,842	1,962	5·0	3·0	5·0	46·0
	3 sheets of zinc .	1,014	0·21	4·25 press.	5·0 "	1,183	1,262	0·7	33·0	53·0	21·0
V	3-hole wire . .	1,074	1·26	0·05 "	0·8 "	3,009	3,206	2·7	22·0	38·0	167·0
	4 sheets of zinc .	1,056	0·22	3·30 "	3·7 "	638	678	0·5	56·0	80·0	36·0
VI	3-hole wire . .	1,289	1·42	0·00 "	0·5 "	2,409	2,566	8·5	10·0	8·5	55·0
	5 sheets of zinc .	1,500	0·16	4·40 "	4·7 "	785	837	5·5	46·0	55·0	15·0
VII	3-hole wire . .	1,276	1·49	0·00 "	0·5 "	2,522	2,687	3·8	9·0	5·5	30·0
	4 sheets of zinc .	1,185	0·21	4·00 "	4·1 "	945	1,007	4·9	37·0	45·5	12·0
VIII	3-hole wire . .	1,300	1·27	1·00 vacuum	0·4 "	1,856	1,977	2·6	6·0	4·0	24·0
	4 sheets of zinc .	1,186	0·16	3·00 press.	3·5 "	715	761	5·2	49·0	47·0	10·0
IX	3-hole wire . .	1,184	1.23	0·67 "	0·2 "	1,583	1,687	0·5	4·0	2·6	17·6
	4 sheets of zinc .	1,669	0·17	5·00 "	5·6 "	1,008	1,076	3·0	46·0	39·0	9·5
X	3-hole wire . .	1,192	1·48	0·04 "	0·5 "	2,663	2,840	7·0	10·5	8·0	40·0
	7 sheets of zinc .	2,099	0·096	12·25 "	12·3 "	815	867	10·0	56·6	61·0	7·0
XI	3-hole wire . .	1,565	1·45	0·00 "	0·0 "	1,088	1,159	4·5	1·0	1·0	30·0
	3 sheets of zinc .	2,541	0·24	2·67 "	2·6 "	756	814	5·2	24·0	19·0	23·0

APPENDIX II.

List of Formulas[1] used in the Experiments.

$$H = \frac{h}{w^k} \quad \ldots\ldots\ldots \quad (1)$$

where H = metres of air; h = pressure in millimetres of water; w^k = weight of 1 cubic metre of air in kilograms at the atmospheric pressure and temperature.

$$V = 4\sqrt{h} \quad \ldots\ldots\ldots \quad (2)$$

where V = velocity of air in metres per second at the end of the pipe (z), and h = pressure in millimetres of water.

$$\text{Theoretical HP.} = \frac{Q \times w^k \times H}{75} \quad \ldots\ldots \quad (3)$$

where Q = quantity of air delivered in cubic metres per second, w^k, and H being as above.

$$\text{Mechanical efficiency} = \frac{\text{theoretical HP.}}{\text{I.HP. required to drive the fan only}} \quad (4)$$

$$\text{Pressure efficiency} = \frac{g\,H}{U^2} \quad \ldots\ldots \quad (5)$$

where g = acceleration of gravity, and U = speed of circumference of vanes in metres per second.

$$\text{Volumetric efficiency} = \frac{Q}{U \times r^2} \quad \ldots\ldots \quad (6)^{[2]}$$

where r is the radius of the vanes in metres.

$$\text{“Ouverture”} = \frac{Q}{\sqrt{g\,H}} \quad \ldots\ldots\ldots \quad (7)$$

$$\left.\begin{aligned}\text{Equivalent orifice (in square metres)} &= \frac{Q}{0{\cdot}65\sqrt{2\,g\,h \times \frac{1{,}000}{w^k}}} \\ &= \text{“Ouverture”} \times 1{\cdot}088 \quad \ldots\ldots\end{aligned}\right\} \quad (8)$$

[1] These formulas are expressed in metric measures which were used by the Author. The results (Appendix I) are tabulated in English measures to accord with the text.

[2] Volumetric efficiency was first used by Prof. Rateau, who recommends for fans with two inlets $\frac{Q}{U\,r^2}$, and for fans with one inlet $\frac{2\,Q}{U\,r^2}$.

APPENDIX III.

Experiments made by the Prussian Mining Commission in 1884 on the Measurement of Air in a Pipe by Different Methods, from a Large Air-Holder at the Breslau Gas-Works.[1]

A spare gas-holder was used for measuring the volume of the air. It was 85·3 feet in diameter, contained 70,634 cubic feet, and served to check the other methods adopted by the Commission. The tests were probably the best that have been published on the measurement of air by the following methods:— 1st, by anemometers; 2nd, by Pitot tubes; and 3rd, through circular and square orifices. The practical questions the Commission endeavoured to solve by using this holder and causing the air to pass through a pipe, were the following:—

1st. Do the formulas generally used for standardizing anemometers in a circular path in still air give correct results or not?

2nd. Can the instrument known as the Pitot tube be applied practically for measuring the speeds of air, and if so what formula should be used for calculating the speed and quantity of air?

3rd. May the fall in pressure between one side and the other of a thin orifice interposed in a pipe be used for calculating the quantity of air, and, if so, what formula should be applied?

4th. What is the loss of head due to friction in regard to the length and diameter of the pipe used?

About eighty careful experiments were made, and the results and calculations appear to have been well checked. The cast-iron pipe was 14·3 inches in diameter and 33 feet long. For stopping and starting the anemometers quickly and accurately, an electrical arrangement was adopted. The vertical fall of the air-holder in several places was carefully determined electrically. The first series of experiments in 1884 was made with the air-holder at a water-pressure of 2¼ inches, but in the 1885 tests, the holder was loaded and the pressure was increased to 4½ inches of water. The density and temperature of the air were noted, and the experiments were made during the autumn, to avoid the heating effect of the sun upon the wrought-iron holder. U-gauges were fixed at different parts of the pipe. A Pitot tube was used for measuring the dynamic pressures of air, not only at the centre and at two-thirds of the radius distant from it, but also round the inner circumference of the pipe. The circular orifices used in these experiments measured 7·03 inches and 9·96 inches in diameter. The square orifice measured 6·26 inches along the side. The rectangular orifice was 9·17 inches by 4·45 inches. The experimental coefficient determined for the circular orifices was 0·64, and for the square and rectangular orifices 0·61. Four Casella anemometers and one Robinson anemometer were tested. The Paper gives all the detailed results of the experiments. The conclusions only need be added here.

The Casella anemometers, previously tested in the usual way at the end of a

[1] Summary of Report by Mr. Althans (see p. 268).

radius bar and compared with direct measurement of air from the holder, showed variable errors, the excess ranging between 7 per cent. and 13 per cent. Anemometer readings should therefore be accepted with much caution, as they generally give, when tested in a circular path, results higher than the true quantities. In the 14·3-inch cast-iron pipe a considerable difference in speed was found at different parts, and in the same vertical plane. The centre gave the maximum speed and pressure, and the inner circumference the minimum; the mean speed of air was found to be at two-thirds of the radius from the centre of the pipe. With regard to the resistance to the movement of the air in the pipe used, the following are the conclusions deduced from these experiments and given in the Report:—1st. That the resistance of the air increases as the square of its speed in the pipe. 2nd. The resistance to the air in the pipe decreases as the diameter of the pipe to the power $\frac{11}{8}$. 3rd. The resistance of air in the pipe increases as the density of the air to the power $\frac{2}{3}$.

These conclusions apply to pipes of cast-iron only. To obtain correctly the quantity of air by means of a Pitot tube the following formula is given:—

Velocity of air in metres per second

$$= 4 \cdot 265 \sqrt{\frac{\text{pressure, in m/m head of water}}{\text{density of air}}}.$$

This formula involves the condition that the air is at a temperature of zero Centigrade. If it is altered for the warmer temperatures of air in the Author's experiments, it will be very nearly the same as that used by him and given in Appendix II.

The result of these experiments showed that all three methods of measuring air—namely, by Pitot tubes, orifices, and anemometers, give accurate results within the limits of these tests, so long as the proper corrections are made and the coefficients mentioned are used.

(*Paper No. 2881.*)

"Cylindrical Bridge-Piers: New Zealand Midland Railway."

By Henry William Young and Walter Cleeve Edwards,
Assoc. MM. Inst. C.E.

Most of the bridges in New Zealand cross streams which flow in channels of shingle or other alluvial drifts, subject to constant change from the processes of scour and deposit. Floods also occur, when a tiny stream becomes a wide foaming river bearing down large quantities of driftwood and uprooted forest trees. Under these conditions, the most suitable and usual forms for bridge-piers are those constructed either of driven piles, or of cast-iron cylinders sunk by pneumatic processes and filled with concrete. In timber-bearing streams, the bridge-piers must be capable of resisting the impact of heavy masses, and the piles must be driven well below the limits of possible scour. Driving has been successfully accomplished in most difficult cases by the use of round piles of Australian ironbark, varying from 12 inches to 16 inches or 18 inches in diameter, shod with cast-steel shoes of a hollow conical form weighing 100 lbs. each, and driven by rams weighing 35 cwt., falling through a height of between 6 feet and 10 feet. One such pile, after having been driven through 15 feet of tight gravel and boulders at the rate of forty-eight blows to a lineal foot, from a monkey weighing more than 35 cwt. falling 10 feet, was on withdrawal found to be quite uninjured. As a rule, the scour in shingle beds at bridge-piers does not exceed, and seldom reaches, a depth of 15 feet below the normal bed of the stream; but whenever it occurs about piled or cylindrical-piers, it is advisable to deposit in the cavity around them an apron of heavy angular stones or boulders to ensure immunity from further erosion. For first-class bridges, piers consisting of two cylindrical columns, ranging between 4½ feet and 8 feet in diameter, have been extensively adopted for upwards of twenty-five years.

The principal object of this Paper is to give some account of the methods, processes, and plant used in cylindrical bridge-piers built since 1887 on the New Zealand Midland Railway. The bridges

consist of series of 66-foot lattice- or plate-girders, supported on piers composed of two columns of cast-iron cylinders 4 feet 6 inches in internal diameter, sunk with the aid of pneumatic pressure and filled with concrete. The bases of some of these columns are enlarged by taper-pieces with 6-foot cutting-rings, Fig. 1, Plate 3, while others are 4 feet 6 inches in diameter throughout, excepting where the cutting-edge projects to 5 feet, Fig. 2. Six bridges of these types have been constructed, viz.:—

1. Arnold River bridge	six 66-foot lattice-girders.
2. Nelson Creek „	five „ „ „
3. Ahaura River „	ten „ „ „
4. Mawheranui River bridge . .	eleven 66-foot plate-girders.
5. Mawheraiti „ „ No. 1	ten „ „ „
6. „ „ „ No. 2	four „ „ „

The height of all the bridges has been determined by the highest known flood level, and is arranged to give a safe amount of clearance under the girders. The metal in all cylinders is 1⅛-inch thick, the junction ends having feathered flanges with bolt-holes. The joining edges of the ends of the cylinders project slightly beyond their flanges, and are machined so that they fit neatly together and in accurate alignment. The flanges of joining rings do not meet, as the edge projections cause a space between them, which is securely packed so as to be air- and water-tight, the flanges being fastened together with 1-inch bolts. The highest cylinder ring, Figs. 3, which has no flange on its upper end, is of suitable length to complete the required height of column, and is finished with a capital which slips over and is bolted to it, a few inches of adjustment for height being possible. The capital is kept in position by distance-studs and bolts, and is thoroughly secured by the concrete filling. With cylinders of larger diameter, or where the weight of the pieces is limited by conditions of transport, the rings are cast in segments having vertical joints similar in construction to those between the rings. As the smaller cutting-rings, used where the nature of the foundations and the height of the piers permitted, were to some extent experimental, it may be interesting to compare their advantages with those of the larger rings. The former saved about £50 per pier in concrete and iron, exclusive of the saving due to the reduction of excavation by two-sevenths. The cutting-rings of an internal diameter of 6 feet allow two men to work on the bottom, while those of 4 feet 6 inches diameter give room for only one man. In certain strata it is expedient to have two men in the bottom while sinking a cylinder. In three bridges experience was distinctly in favour of the smaller rings, and proved

that they can be used with advantage under fairly favourable conditions.

In the construction of the piers, the essentials may be classed under the heads of staging with hoisting-gear, pneumatic plant and appliances, placing and erecting, loading, sinking and filling with concrete. The staging, Figs. 4, usually consists of two combined structures, one comprising the erections required for guiding and controlling the cylinders, each formed of six driven piles with their caps and framing, and collectively called a "pig-sty"; the other consisting of piles, braces, caps and stringers between the "pig-sties" for the whole length of the bridge, employed to carry the travelling gantry which is used both for pier and girder construction. It was generally found sufficient to drive the piles of the temporary staging to a depth of 8 feet with a 1-ton monkey, from an outrigged staging pushed ahead of the fixed staging. As the staging was completed, iron rails were placed along the two outer stringer beams, and on these a movable gantry, carrying an overhead crab-winch, commanded the bridge works from end to end. In some cases, where the bridge crosses the bed of a river which is usually almost dry, the "pig-sties" only have been used; the conveyance and hoisting being performed from a temporary tramway laid on the bed of the river, or by overhead ropes and travellers worked from bank to bank.

The pneumatic plant includes a driving-engine, air-compressor, air-receiver, connecting-pipes and air-lock. In one very effective arrangement, the engine and compressor were combined in a direct-acting form, the steam-cylinder being 7 inches in diameter with a 16-inch stroke, and the air-cylinder 9 inches in diameter. The steam is supplied from a vertical boiler. The engine and boiler occupy one side of the engine-shed, the other containing the receiver. The air is cooled if necessary by wet sacks spread over the receiver and the air-lock. In another arrangement the power is taken by belt from a 10-HP. portable engine and applied to the driving-wheel of a 9-inch water-jacketed air-cylinder fixed on the top of the receiver. On the whole, the direct-acting engine and compressor with a separate receiver is to be preferred. It can be made as easily portable and for the same cost as the alternative design, and requires less attendance.

The air-lock, Figs. 5, forms the most important feature of the pneumatic plant. It is cylindrical in form, constructed of ⅜-inch boiler-plate, stayed and strengthened, furnished with a door on the side, a manhole for access to the cylinders in the floor, two reversible shoots projecting outside from opposite sides of the chamber,

and the necessary air-piping, stop-cocks, pressure-gauge and dead lights. A length of rubber piping connects the iron air-pipe with the air-lock. The windlass is worked from the outside, being contained in an air-tight casing bolted on the top of the chamber, the axle passing through the casing in air-tight packing, Figs. 6. The two shoots, Figs. 7, are essential to rapid work. They are simply iron tubes, rectangular in section, with movable air-tight end glands, and are constructed so as to be reversible with either a downwards or an upwards slope from the air-lock. The glands and clamping-bolts have rubber packings, and are easily fixed or removed. Those for the air-lock openings run up and down in slides within the chamber, and are balanced by counterweights hung on light wire-ropes attached to the glands and passing over pulleys. The glands at the outer ends of the shoots are hinged so as to open clear, and are fastened when closed by a hinged clamping-bolt, Figs. 8. The manhole-door, Figs. 9, on the side of the air-lock is hung and closed in a similar manner to those of the shoots. The door between the air-lock and the cylinder, Fig. 10, is hinged to open downwards, and is closed and fastened from above by a clamp bar. All the air-pipe arrangements can be manipulated within the air-lock, and provide means for letting air in or out of the air-lock and cylinder respectively. A life-line secured and kept within the air-lock is provided in case of sudden flooding of the cylinder or of accident to the rope or winch. The bed-plate, which can be changed to suit the size of the cylinder, is a casting bolted to the flanged bottom of the air-lock and to the top flange of the cylinder.

When working, the air-lock man remains inside, and the chamber is kept under pressure with the door open between it and the cylinders, except when men have to pass in or out at changes of shift or other times. The cylinders are, if possible, kept constantly under pressure. When excavated material is passed out, the air-lock man sends down the empty bucket, the windlass being worked by the men outside according to his signals; and on its return full he tips it into one of the shoots, which is then open at the chamber end and closed at the other. Whenever one shoot is full, the air-lock man closes and secures the gland at his end, and signals to the attendant outside, who opens the discharge end and empties the shoot, having previously prepared the other shoot for filling. The chamber man after filling and closing one shoot, opens and fills the other, and by this alternate use of the two shoots, the work is proceeded with continuously without alteration of the air-pressure. Under fairly favourable conditions,

the windlass is thus kept constantly going, and sinking proceeds as quickly as in an open shaft. Four men are required exclusive of sinkers, one being in the air-lock, two at the windlass, and one attending to the shoots and to the guidance of the cylinder.

The staging and plant being ready, a cylinder is placed and erected ready for sinking. If its position happens to be on the bank or dry bed of a river, an open excavation is first made slightly below the water-level. The cutting-ring is then brought forward by the gantry and is adjusted in position. Other rings with air-tight joints are then bolted on to it until a column is built passing up through the "pig-sty" framing and above the staging to the greatest convenient height. The column is then carefully plumbed and secured in a vertical position by the framing and wedges. The tubing and concrete kentledge subsequently described is inserted as the building proceeds, and is completed so far as is necessary; after which, if possible, it is left for a short time to give the concrete time to set. When the column is ready for use, the air-lock is placed on the top of it and bolted with an air-tight joint to the upper flange of the topmost cylindrical ring, when the air-connections are made and sinking under pressure can begin. If the cylinders have to be pitched in water, the cutting-ring and a convenient number of other rings are put together in the "pig-sty" above the water-level. The column thus constructed is carefully lowered and guided into its exact position, and completed as in the previous case, excepting that the tubing and loading are executed under pressure. When pitching a column in a strong current of water, it should be placed a few inches up-stream from its true position, and afterwards moved down by wedging. If placed out of position down stream its adjustment is difficult. To prevent the cylindrical column from being forced upwards by air-pressure, and to insure its descent as the sinking proceeds, it is loaded until it overcomes skin-friction and other resistance, whilst yet thoroughly under control so that it may be readily hung up when necessary. If the loading is insufficient, the column may be lifted with an increase of air-pressure or may fail to descend as the excavation below it is performed, in which event an inrush of drift may occur if the ground is loose. Under favourable conditions concrete loading is sufficient, but where more weight is necessary, rails or other available materials are placed on staging attached to the air-lock bed-plate.

In applying the concrete loading which forms part of the permanent filling, a feature called the "bell" is first formed. This is done by setting up an internal frame of "bell-irons," con-

sisting of 2-inch by $\frac{3}{8}$-inch rods bolted to the flange of the cutting-ring joint, sloping upwards at an angle of 60° towards and bolted to an angle-bar ring 2 inches by $\frac{3}{8}$ inch and 18 inches in diameter, placed horizontally in the middle of the cylinder. Tapering lagging-boards 1 inch thick are then laid over the sloping iron frame which connects the flange of the cylinder with the ring, and upon the lagging concrete is laid. A length of tube, 18 inches in diameter, made of 3-inch by 1-inch timber staves, 6 feet long, bound with light hoop-iron, is then set up above the central ring, and is kept concentric with the cylinder. The annular space between the tube and the cylinder is filled with concrete, another similar length of tube and concrete work is constructed, and so on until the required height is reached. The bell-irons, lagging and tubing, which are easily removable, remain until the sinking is completed, when they are taken out. It is advisable to use more cement in making the loading than is required for ordinary concrete as time seldom admits of its setting, and sinking has often to proceed immediately after the concrete is placed. A safe height should always be left between the bottom of the cutting-ring and the bell, especially where sand or soft material may be met with; otherwise a sudden drop of the column would be dangerous to the men engaged below. The concrete loading is excavated with or without air-pressure as circumstances may require. Sheet-iron bells and tubes have been tried. They were easily set up, but were difficult to unfasten and detach from the concrete, and were abandoned in favour of the timber lagging.

When constructing and sinking a pier, the two columns forming it are under execution at the same time, the air-lock being moved from the one to the other as the operations require. When work under pressure is proceeding, all joints in the apparatus should be frequently examined, and leakage should be carefully guarded against. The compressor should be kept in good order and under careful management, as fitful and unsteady pressure is exceedingly trying to men working under it, and allows the water-level to fluctuate in the cylinder. Success in sinking depends greatly on the intelligence of the engine-driver, who, instead of remaining in the engine-room and working only by the signals, should watch the work carefully and notice the bubbles of air that ascend outside the cylinder. These tell to an experienced eye in what degree the signals for more or less air are to be acted on—the object being to maintain exact equilibrium between the air-pressure within the cylinder and the water-pressure at the bottom of it. Special care must be taken to prevent breakage in the pipe and connections,

and thoroughly to secure the air-lock doors when under pressure. If possible, a column, when once started, should be kept moving until it reaches bottom, as in some ground it is liable to silt up and become plugged if sinking be stopped. Such plugging is often difficult to break through by any air-pressure that can be brought to bear upon it. It is then necessary to probe the bottom round the cutting-ring with bars, and when the level of the water in the cylinders is reduced below that of the river, the bottom crust or plug is further destroyed by stopping the engine and suddenly relieving the air from the cylinder, when the inrush of water from the outside scours up the deposit. During the process of sinking, the column may take a list to one side, or may move bodily out of its proper position from unequal settlement or from the force of the current. By careful manipulation of the wedges which bind and guide the column within the "pig-sty" frames, accurate results can generally be obtained. If, during sinking in loose ground, the position of the bottom of the cylinder is correct, but is not plumb, it can be brought vertical by wedging and careful excavation. If the column is out of position at the bottom, the top is first brought over in a direction opposite to its true position, so that the downward inclination is towards it. It is then sunk for a short distance and wedged plumb, and the process is repeated if necessary until it is accurately in position and vertical. In the bridges referred to, the eye can detect no irregularity in the range of the completed piers. When men are not at work in the cylinders, all manhole-doors should be left open, so as to prevent the accumulation of foul gas. On more than one work in the colony serious accidents have happened from explosions caused by inflammable gas met with during sinking.

The concrete for filling the cylinders is mixed on the air-lock staging, and consists of Portland cement and river gravel. When filling cylinders, the air-lock shoots are reversed so as to incline upwards, and the concrete is passed in by operations similar to those used in passing out the spoil. After the "bell" and tube have been removed, the bottom is lined with tarred canvas; the cylinder-men ascend into the air-lock, the concrete is dropped from the shoots into the cylinders, and after a sufficient quantity has been deposited, the men descend to trim and ram it, the process being repeated until the filling is above water-level, when the air-lock is removed and the concrete is finished to the top. When depositing concrete, the air-pressure should be kept steady and as low as possible, gradually decreasing so as not to blow through the bottom and disturb the cement. The column is completed by

adjusting, bolting, and fitting on the cap-ring. The corbels are bedded on the concrete filling of the cap-ring and are secured by holding-down bolts built in, Figs. 11.

Where the columns are high and are not rigidly connected by cross girders, it is advisable to couple them so as to strengthen the piers against lateral impact or pressure of drift timber. Horizontal stays with cross bracing, unless well above flood-level, are liable to catch and retain drift wood. To obviate this, horizontal cast-iron tubular stays are used, the ends resting in cast-iron sockets bolted to the cylinders. These tubes are made about 6 inches shorter than the distance between the bearings, and the spaces thus left are filled in with cement so as to make a sound joint without the necessity for machining the ironwork to an exact fit. 2-inch iron bolts, with nuts at each end, pass through the pairs of cylinders diametrically and also through the bosses and tubes. The bosses have movable covers to admit the tube-ends and cement, and resemble turned base mouldings. The cylinders sunk passed through gravel with occasional layers of boulders, silt, or other alluvial deposit. The bottom was of soft sandstone locally known as "sand reef," formed of deep-sea sludge. In some cases the cylinders were sunk for a few feet into this "sand reef," which can be excavated with picks and gads.

The work described was executed for the New Zealand Midland Railway Company, the engineer-in-chief being Mr. Robert Wilson, M. Inst. C.E.; Mr. C. N. Bell, M. Inst. C.E., being the resident engineer, until his retirement at the end of 1891. The Authors were respectively Chief Assistant Engineer and Engineer Resident on the Construction.

The Paper is accompanied by five photographs and by four sheets of tracings, which have been used in the preparation of Plate 3.

(*Paper No. 2853.*)

"Experiments on the Torsional Strength of Solid and Hollow Shafts."

By WILLIAM CHARLES POPPLEWELL, M.Sc., and ERNEST GEORGE COKER, B.Sc., Wh.Sc.

THIS Paper describes a series of experiments carried out by the Authors in the Fulton Engineering Laboratory of the University of Edinburgh, for the purpose of determining the behaviour, when tested to destruction under similar conditions, of hollow shafts, compared with that of solid shafts of equal strength as calculated by the usual, though incorrect, method.

It has been considered possible, after making certain assumptions, to determine the dimensions of two shafts of the same material, one hollow and one solid, which shall be of equal torsional strength, *i.e.*, which shall require equal twisting-moments to produce fracture. The usual method is by a formula involving the assumption that the shafts remain perfectly elastic up to the point of fracture. This is not a fair assumption, because it is well known that all materials used for shafts in engineering work lose their elasticity some time before fracture takes place, and become more or less plastic. It was, however, on this assumption that the Authors proportioned their torsion specimens.

Let R be the radius of a solid shaft of a certain material, R_1 the external radius of a hollow shaft of the same material, R_2 the internal radius of the latter, f the maximum shear-stress in the shaft in question in pounds per square inch, T_S the twisting-moment in inch-pounds necessary to fracture the solid shaft, and T_H the twisting-moment in inch-pounds required to fracture the hollow shaft.

From a right section of the shaft let an elementary ring be taken of width $d\,r$, and mean radius r. So long as the material remains elastic, the shearing-stress s on this ring will be proportional to

its distance from the centre, and expressed by $f\,\frac{r}{\mathrm{R}}$ for a solid shaft, and the moment of resistance of this ring will be

$$\frac{2\,\pi f}{\mathrm{R}}\,r^3\,d\,r;$$

also

$$\mathrm{T_S} = \frac{2\,\pi f}{\mathrm{R}}\int^{\mathrm{R}} r^3\,d\,r$$

$$= \frac{\pi}{2}\,f\,\mathrm{R}^3 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In the same way it may be found that

$$\mathrm{T_H} = \frac{\pi}{2}\,f\,\frac{\mathrm{R}_1^4 - \mathrm{R}_2^4}{\mathrm{R}_1} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Then, in order that the torsional strengths of the hollow and solid shafts may be equal, $\mathrm{T_S}$ must be equal to $\mathrm{T_H}$, and hence is obtained the relation

$$\mathrm{R} = \sqrt{\frac{\mathrm{R}_1^4 - \mathrm{R}_2^4}{\mathrm{R}_1}}.$$

It should be remembered that the above relation holds good only so long as the material is elastic.

If, now, the material be supposed, instead of being elastic, to be perfectly plastic, the shearing-stress will be constant over the whole section, and in this case

$$s = f = \text{constant}.$$

The resistance of the ring will be

$$2\,\pi f\,r^2\,d\,r;$$

also

$$\mathrm{T_S} = 2\,\pi f \int_0^{\mathrm{R}} r^2\,d\,r$$

$$= \tfrac{2}{3}\,\pi f\,\mathrm{R}^3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Similarly

$$\mathrm{T_H} = 2\,\pi f \int_{\mathrm{R}_2}^{\mathrm{R}_1} r^2\,d\,r$$

$$= \tfrac{2}{3}\,\pi f\,(\mathrm{R}_1^3 - \mathrm{R}_2^3) \quad . \quad . \quad . \quad . \quad . \quad (4)$$

In order that $\mathrm{T_S}$ may be equal to $\mathrm{T_H}$ in this case

$$\mathrm{R} = \sqrt[3]{\mathrm{R}_1^3 - \mathrm{R}_2^3}.$$

Equations (1) and (2) give the relations between the final twisting-moment, the shearing-stress and the dimensions of a solid and hollow shaft respectively, the material of which is perfectly elastic under all stresses. In the same way equations

(3) and (4) give similar relations when the material is plastic under all stresses. They both refer to extreme conditions which do not obtain in the ordinary materials used for engineering purposes. The metals most employed for shafts are wrought-iron and steel, the behaviour of which under a torsional stress is not very dissimilar. Up to a certain point, shafts of these materials are perfectly elastic, and equations (1) and (2) hold good. But as the twisting-moment increases, the elastic limit is reached and passed, and the material assumes a partially plastic condition—beginning to manifest itself at the outer layers of the shaft which are under the greatest stress, and gradually penetrating inwards Under the elastic conditions, the shearing-stress in the shaft at any point of a section is proportional to its distance from the centre; but beyond the elastic limit this no longer holds, and the stress is more evenly distributed over the whole area—the relations between the shearing-stress, breaking-moment and dimensions of the shaft more nearly approaching the conditions expressed in equations (3) and (4). As will be shown from the results which follow, the exact relations between these quantities depend to a great extent upon the character of the material, and vary with different materials.

The experiments undertaken by the Authors were for the purpose of ascertaining how far the relations expressed in equations (1) and (2) hold, when pairs of shafts proportioned according to these expressions are tested to destruction. For this purpose three materials were selected, having different molecular structures, viz., wrought-iron, mild steel, and cast-iron. In order to fully determine the character of each metal, not only were torsion specimens prepared and experimented upon, but also a series of tension and shearing tests were carried out upon the same metals.

Of the three materials experimented upon, the cast-iron was made from a mixture of four parts of No. 3 Shott's pig-iron and six parts of No. 3 Clyde hæmatite, containing 3 per cent. of carbon, of which 2·17 per cent. was uncombined, as graphite, and 0·83 per cent. was combined; the wrought-iron test-pieces were turned from a 1-inch bar of merchant iron; the steel bars being also turned from a 1-inch bar of ordinary mild steel.

The specimens tested may be classified thus :—

(*a*) Two turned tension-bars of each metal.

(*b*) Two shearing specimens of each metal.

(*c*) Five solid shafts of each metal, about 0·47 inch in diameter and 5 inches long, tested under a torsional stress.

(*d*) Five hollow shafts of each metal, about 0·5 inch external diameter, 0·3 inch internal diameter and 5 inches long, tested under a torsional stress.

The Tension Tests.—These were carried out in the usual way in the 100-ton Buckton testing-machine of the Fulton Laboratory. A Kennedy extensometer was used for measuring the elastic extensions. The results are shown in Table I.

TABLE I.—TENSION TESTS.

Material.	Length of Test-Part.	Maximum Stress.	Stress at Elastic Limit.	Value of E.
	Inches.	Tons per Sq. Inch.	Tons per Sq. Inch.	Tons per Sq. Inch.
Wrought-iron	10	23·65	15·85	13,513
	10	23·23	15·48	13,694
	Mean . .	23·44	15·66	13,603
Mild steel	10	25·82	17·19	12,820
	10	26·09	17·63	14,925
	Mean . .	25·95	17·41	13,872
Cast-iron	..	Broke in jaws	..	5,181
	..	9·74	..	4,854
	Mean . .	9·74	..	5,017

The Shearing Tests.—In these tests the bars were broken in double shear, and across an area situated at the bottom of two grooves turned on the surface of the specimens. The results are given in Table II.

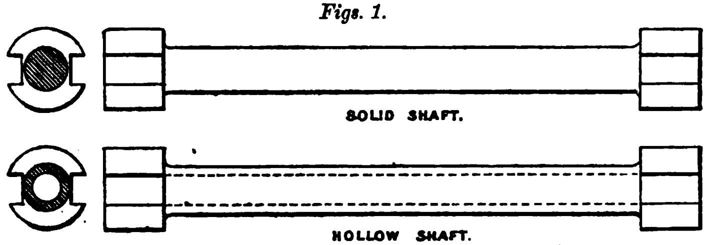
TABLE II.—SHEARING TESTS.

Material.	Diameters of Grooves.	Shearing-Stress.
	Inch.	Tons per Square Inch.
Wrought-iron	0·820 and 0·788	20·43
	0·817 „ 0·820	20·30
	Mean . .	20·37
Mild steel	0·807 and 0·808	22·50
	0·810 „ 0·815	22·39
	Mean . .	22·45
Cast-iron	0·816 and 0·824	9·54
	0·808 „ 0·820	7·33[1]
	Mean . .	9·54

[1] There was a flaw in this specimen.

The Torsion Tests.—Before carrying out these tests it was necessary to proportion the specimens properly, *Figs. 1.* The hollow shafts were first prepared, being roughly turned to an external diameter of rather more than 0·5 inch, and then carefully bored throughout their length to an internal diameter of 0·315 inch. When the hole had been finished off, the shafts were carefully turned to an outside finished diameter of 0·5 inch, the enlarged ends completed, and the necessary keyways cut therein. This having been done, the shafts were carefully measured to one-thousandth of an inch, inside and out, by sets of five, that is, a set belonging to one metal at a time. It was found that the diameters did not vary in any one set more than three-thousandths of an inch from the mean diameter. From the measurements thus obtained, the diameter which a solid shaft of the same material should have was determined by the formula. The machine in which the torsion tests were carried out was a special torsional

Figs. 1.

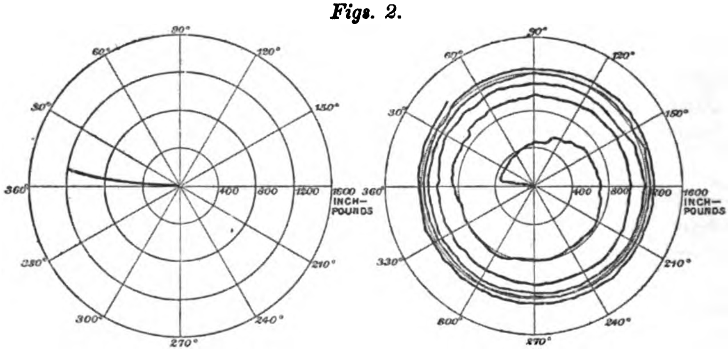


testing-machine constructed by Messrs. Joshua Buckton and Co. of Leeds. The machine was designed purely as a torsional machine. It is of the single-lever kind. The beam is carried on a knife-edge, and increase of twisting-moment is effected by increasing the distance of a travelling jockey-weight from the knife-edge. The specimens tested are held at one end by the beam, and at the other by a heavy worm-wheel which is actuated by a single-pitch worm turned by a hand-wheel keyed on to the same shaft. The angles turned through were ascertained by noting the revolutions or parts of revolution of this hand-wheel. The worm-wheel and worm were machine-cut and of heavy design, so that there was no likelihood that angles measured in this indirect way would differ to any material extent from the true angles. The Authors think that the elastic compression of the ends of the specimens, and possibly the slight deformation of the worm-gearing under the load, would render the angles of twist within the elastic limit insufficiently accurate for such purposes as the

determination of modulus of torsional rigidity; but they are of opinion that the degree of accuracy is ample for the comparative purposes for which the experiments were undertaken. In addition to the appliances used for measuring the twisting-moments and angular deflections, an apparatus for the purpose of drawing an automatic diagram is attached to the machine. The diagram produced is a polar one, the pencil having a radial motion, proportional to the movement of the jockey-weight, over a revolving disk the angular movement of which corresponds with the twist of the specimen shaft from which it receives its movement. Diagrams of this kind were taken in most of the experiments. Two specimens are shown in *Figs.* 2.

From notes made during the progress of the experiments, the Authors have extracted the chief and most important results. In Table III are collected all the results of the torsion tests which

Figs. 2.



CAST IRON. WROUGHT IRON.

are of importance. In this Table may be seen at a glance the results obtained in the testing of each individual shaft. The mean results for each set of five bars are given, and from these are calculated the shearing-stresses in the metal. The maximum shearing-stresses, calculated by equations (1) and (2) on the assumption that the bars are at all times elastic, are given; as well as the maximum shearing-stresses calculated by equations (3) and (4), assuming the metal to be perfectly plastic at the point of rupture.

In Figs. 3 and 4, Plate 4, are plotted respectively curves showing the twisting-moments and the corresponding angular deflections up to and just beyond the elastic limit, for three cases respectively of solid and hollow wrought-iron shafts. Similar sets of curves for solid and hollow steel specimens are shown in

Figs. 5 and 6. In Figs. 7 and 8 are given complete curves up to the point of fracture for solid and hollow cast-iron bars respectively. All the curves are plotted from the results observed in testing individual shafts. In Fig. 9 are plotted two complete diagrams, one being a mean diagram for the five solid wrought-iron shafts, and the other a mean diagram for the five hollow wrought-iron shafts. Figs. 10 and 11 contain corresponding pairs of curves for steel and cast-iron respectively.

Turning to the results of the torsion tests as given in the six last columns of Table III, it will first be seen that the shearing-stresses in the shafts at the elastic limit in column A are greater for the solid than for the hollow shafts both in the case of the wrought-iron and the steel. The actual excess in the case of the wrought-iron is 6·3 per cent., and for the steel, 12·5 per cent. These stresses are calculated by equations (1) and (2) on the assumption that the metal is perfectly elastic.

In column D are repeated the ultimate shearing-stresses already given in a previous Table as determined from direct shearing experiments. In columns B and C are given the ultimate shearing-stresses in the torsion bars, calculated on the assumption respectively of perfect elasticity and perfect plasticity at the point of fracture. The first assumption is incorrect, as is amply proved by the fact that all the values in column B greatly exceed the corresponding values of column D. Those given in column C agree much more closely with those of column D, and clearly show that, in the case of wrought-iron and steel, the metal assumes an almost perfectly plastic condition before the point of fracture is reached. The figures show that in the case of cast-iron also, the variation of stress at the point of fracture does not follow the elastic law, but is more equally distributed over the whole section. In practice, it is necessary to keep the stresses well within the elastic limit, and the experiments seem to show that at this limit no great inaccuracy will be produced when designing hollow and solid shafts of equal strength by using the relation

$$R = \sqrt[3]{\frac{R_1^4 - R_2^4}{R_1}}.$$

In designing a cylindrical shaft to resist a given twisting-moment in ordinary work, it is, however, usual to start from the basis of the ultimate shearing-stress of the metal to be used, a quantity the value of which can only be obtained by means of direct shearing experiments. This ultimate shearing-stress is multiplied by a factor of safety for the safe stress, and equation (1) or (2) is used

TABLE III.—RESULTS OF TORSION TESTS.

Number of Test.	Material.	Description.	Length.	External Diameter.	Internal Diameter.	Moment at Elastic Limit.	Final Twisting Moment.	Final Angle of Twist.	Shearing-Stress at Elastic Limit.	Shearing-Stress from Equations (1) and (2).	Shearing-Stress from Equations (3) and (4).	Shearing-Stress from Shearing-Tests.
			Ins.	Ins.	Ins.	Inch-lbs.	Inch-lbs.	Degr.	Tons per Sq. In.	Tons per Sq. In.	Tons per Sq. In.	Tons per Sq. In.
11	Wrought iron	Solid	5·000	0·469	..	400	1,300	2,153				
12			5·000	0·469	..	450	1,294	2,163				
13			5·000	0·469	..	450	1,353	2,485	(A)	(B)	(C)	(D)
14			5·000	0·469	..	450	1,300	2,334				
15			5·000	0·469	..	450	1,300	2,235				
		Means	5·000	0·469	..	440	1,309	2,274	9·69	28·85	21·64	20·37
16		Hollow	5·000	0·498	0·315	400	1,092	1,132				
17			5·000	0·498	0·315	425	1,100	1,050				
18			5·000	0·499	0·315	400	1,050	994				
19			5·000	0·498	0·315	425	1,140	1,413				
20			5·000	0·498	0·315	425	1,140	1,259				
		Means	5·000	0·498	0·315	415	1,104	1,170	9·11	24·17	20·39	20·37
31	Mild steel	Solid	5·000	0·473	..	475	1,350	2,174				
32			5·000	0·473	..	525	1,370	2,112				
33			5·000	0·473	..	500	1,350	2,018				
34			5·000	0·473	..	500	1,350	1,770				
35			5·000	0·473	..	450	1,350	2,037				
		Means	5·000	0·473	..	490	1,354	2,022	10·53	29·09	21·82	22·45
36		Hollow	5·000	0·500	0·313	475	1,281	1,746				
37			5·000	0·500	0·313	425	1,280	2,236				
38			5·000	0·500	0·313	425	1,300	2,020				
39			5·000	0·501	0·317	425	1,280	1,961				
40			5·000	0·501	0·316	425	1,250	1,926				
		Means	5·000	0·500	0·314	435	1,278	1,978	9·36	27·51	23·15	22·45
51	Cast iron	Solid	5·000	0·473	..	..	725	17				
52			4·990	0·473	..	..	593	12				
53			4·990	0·473	..	..	625	12				
54			4·990	0·474	..	..	624	14				
55			4·990	0·474	..	..	822	24				
		Means	4·992	0·473	..	..	678	16	..	14·56	10·92	9·54
56		Hollow	5·000	0·500	0·313	..	425	7				
57			5·000	0·500	0·313	..	450	8				
58			5·000	0·500	0·313	..	570	11				
59			5·000	0·500	0·313	..	524	10				
60			5·000	0·500	0·313	..	448	8				
		Means	5·000	0·500	0·313	..	483	9	..	10·38	8·83	9·54

to determine the diameter. As the ultimate shearing-stress is the basis worked from, it would seem more logical to employ formulas expressing the relations between the dimensions of the shaft, the twisting-moment and the ultimate shearing-strength of the metal. Such relations are shown by the experiments to be very nearly given by equations (3) and (4).

The slight excess of strength of the solid over the hollow shafts at the elastic limit is no doubt due partly to interference with the molecular structure of the metal by the process of boring, and partly to the fact that it was not possible under the circumstances to detect the elastic limit with great accuracy. If this had been done, the Authors think the difference would have been reduced. In all probability the elastic limit would manifest itself sooner with hollow than with solid shafts in the absence of very delicate measuring-apparatus. The ratio—

$$\frac{\text{Weight of solid shaft}}{\text{Weight of hollow shaft}} \text{ was } \frac{2{,}228}{1{,}514} = 1 \cdot 46.$$

From this the twisting-moments on the bars at the point of fracture per unit weight have been calculated with the following results:—

	Solid.	Hollow.
Wrought-iron, ultimate twisting-moment in inch-lb. .	0·58	0·73
Mild steel " " " .	0·61	0·84
Cast-iron " " " .	0·31	0·32
Wrought-iron, at elastic limit	0·20	0·27
Mild steel " "	0·21	0·29

The conclusions deduced from the experiments are—

(*a*) In all cases the solid shafts are slightly stronger than the hollow shafts at the elastic limit: (*b*) Beyond the elastic limit and up to the point of fracture the solid shafts are much the stronger: (*c*) Weight for weight, the hollow shafts are stronger than the solid shafts both at the elastic limit and at the point of fracture: (*d*) Beyond the elastic limit, the assumptions upon which equations (1) and (2) are based do not hold, and equations (3) and (4) express more nearly the relations which exist.

The Authors desire to express their thanks to Prof. G. F. Armstrong, M.A., M. Inst. C.E., for the facilities he afforded them in prosecuting this research, and for many valuable suggestions during its progress; and to Prof. Stanfield, Assoc. M. Inst. C.E., for his assistance in making the direct shearing-tests.

The Paper is accompanied by thirteen tracings, from which Plate 4 and the *Figs.* in the text have been prepared.

(*Paper No. 2896.*)

(*Abridged.*)

"The Powers of Lighthouse-Lights by Calculation."

By Alan Brebner, B.Sc., Assoc. M. Inst. C.E.

In a Paper on the "Relative Powers of Lighthouse Lenses,"[1] printed in 1893, the Author explained, with two important practical applications, a new method of determining the relative powers of lenses of different form. The purpose of the present communication is to indicate some improvements on that method, and by its further development to show how the actual powers of lighthouse-lights can be determined by calculation.

The forms of the optical instruments in lighthouses being known, it is possible to determine mathematically how they act upon rays of light transmitted by them from their illuminants. It must be remembered, however, that, although it is possible to cut and polish glass to truly plane, spherical, conical and annular surfaces, such work may be done with greater or less accuracy, so that it is not safe to assume that every lens manufactured is true in form.

Uses of the Protractor.—The optical[2] protractor invented by the late Mr. Alan Brebner enables dioptric and catadioptric prism profiles to be drawn without calculation, and, in careful hands, so accurately as to be practically sufficient when such drawings are made of full size; yet even here mathematics are the chief agent, for the protractor in question is a calculating-machine. Anyone who has mastered the easy mathematics required for practical purposes in lighthouse optics will prefer to use them rather than this machine, which cannot be relied on to give radii of curvature with complete accuracy.

Testing of Foci.—The method of procedure in testing dioptric lenses or lens-rings is to place the element in a dark gallery at one end of which is a lamp, L in *Fig. 1*, in the line of the axis

[1] Minutes of Proceedings Inst. C.E., vol. cxi. p. 296.

[2] *Ibid*, vol. xxviii. p. 34.

of the ring, which is held against vertical standards with a vertical white screen behind it. The screen is moved backwards and forwards until the conjugate focus to the lamp is found, say at l. Calling f the distance from the lamp to the lens, f' the distance from the lens to the conjugate focus, and F the principal focal length, then

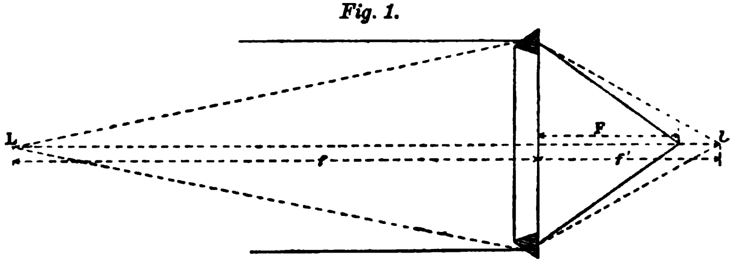
$$\frac{1}{F} = \frac{1}{f} + \frac{1}{f'},$$

or

$$f' = \frac{F f}{f - F};$$

and the value of f' found experimentally should agree with the value derived from the formula. If the former differs too much from the latter, the element is returned to the grinding-machine for rectification. The formula so used is sufficiently accurate for the plano-convex lens-rings generally employed, the distance of

Fig. 1.

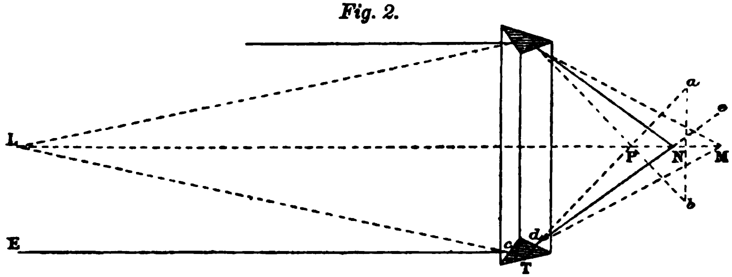


the conjugate focus from the lens by the formula being only about $\frac{1}{200}$ less than the true distance in the case of a first order lens-ring receiving light at an inclination of 30° from the axis. If it be required to test a catadioptric revolving-light element (*Fig.* 2), it is a mistake, though one often made, as Mr. Ribière pointed out in 1894,[1] to apply the formula referred to. If the formula were so applicable, then rays from a lamp at L (*Fig.* 2) would reunite after traversing the catadioptric ring somewhere at M beyond the principal focus N. As a fact, however, they cut the axis at some point P within the point N. The position of the mean point of intersection P in the axis may be calculated by tracing rays from L through several points of the outer refracting side of the profile, and the directive action of the profile may be tested thereby, but not its focussing action. For the point P is not the conjugate focus to L, there being indeed no single con-

[1] Annales des Ponts et Chaussées, August, 1894, p. 211.

jugate focus to it, but a different one corresponding with every axial section of the catadioptric ring, the locus of the foci being a circle such as *a b*. By placing the testing-lamp at E, however, and masking all the ring except a small segment of it at T, bisected by the vertical plane E T N, the formula given above is applicable to the catadioptric profile both in the case of fixed-light and of revolving-light elements. That is to say, on producing d N there is a conjugate focus to E at some point e such that $de = \frac{d\text{N} \times \text{E}c}{\text{E}c - d\text{N}}$ or that $\frac{1}{d\text{N}} = \frac{1}{\text{E}c} + \frac{1}{de}$. The latter method was successfully applied by the Author in 1888 and subsequently. Again, the formula given, whilst accurate enough for the usual plano-convex rings, is not so for spherical dioptric rings, where it is necessary to specially calculate the conjugate foci corresponding with any position of the testing-lamp.

Fig. 2.



Equiangular, Plano-convex and Spherical Dioptric Lenses.—For the purpose of comparing the properties and powers of equiangular, plane and spherical lenses, three such lenses, extending to 31° 18′ from the axis all round, have been designed. These are shown in Figs. 3, Plate 5. The Figs. show how, in the spherical lens, with an inner side where no work is accomplished, all the deviation of focal rays, falling on it normally, has to be made at the outer sides, which are of pronounced curvature with centres situated close to the lens; how, in the plano-convex lens, a large share of the deviation occurring at the inner sides which receive focal rays at increasing angles of incidence, the curvature of the outer sides is less pronounced and the centres of curvature are farther removed from the lens; and how, in the equiangular lens, the curvature of the outer sides, at which the same amount of work is done as at the inner sides, is further diminished.

The plano-convex lens has a focal length of 250 millimetres,

the spherical lens is of the same maximum radius equal to 292·58 millimetres, and subtending the same angle at the focus. The equiangular lens, as calculated, was intended to be of the same maximum radius, but the guess made of the principal focal length, viz., 227 millimetres, was about 7 millimetres short, so that the principal focal length ought to have been 234 millimetres. Rather than calculate an entirely new lens, it was simpler and equally accurate to determine the divergences for the lens of 227 millimetres principal focal length and correct these, multiplying them by $\frac{227}{234}$. Fig. 4, Plate 5, shows half-size half-sections of the three lenses in which there is a common maximum radius of 292·58 millimetres, the principal focal lengths being 234, 250, and 292·58 millimetres for equiangular, plane, and spherical lenses respectively. Table I gives some of the corresponding angles of the three forms of lens.

TABLE I.

	Title.	α	β	γ	δ	$\alpha-\beta$	$\delta-\gamma$
		° ′	° ′	° ′	° ′	° ′	° ′
Equiangular	E − 1 .	22 20	14 23	14 23	22 20	7 57	7 57
	E − 2 .	34 27	21 42	21 42	34 27	12 45	12 45
	E − 3 .	41 5	25 26	25 26	41 5	15 39	15 39
Plane	P − 1 .	15 55	10 19½	18 10	28 29½	5 35½	10 19½
	P − 2 .	25 29	16 20	26 15	42 35	9 9	16 20
	P − 3 .	31 18	19 51	29 57	49 48	11 27	19 51
Spherical	S − 1 .	0	0	25 44	41 37	0	15 53
	S − 2 .	0	0	34 27	59 56	0	25 29
	S − 3 .	0	0	37 33	68 51	0	31 18

In this Table α is the angle of internal incidence of the outermost ray falling on each element, and β, γ, δ are the corresponding angles of refraction, of incidence on the outer face, and of emergence respectively. The deviations by refraction are $\alpha-\beta$ at the first surface and $\delta-\gamma$ at the second. The last two columns of the Table thus show how, in the equiangular lens, the work of deviation of focal rays is the same at inner and outer refracting surfaces; how in the plano-convex lens less deviation is effected

at the inner surface; and how in the spherical lens all the deviation is effected at the outer surface. The sum of the figures of the last two columns for each element gives the inclination of the ray to the axis at the outset, which is not given separately in the Table for the equiangular lens, but coincides with a in the plane lens, and with $\delta-\gamma$ in the spherical lens.

Calculation of Mean Divergences for a Spherical Illuminant.—At the focus of each lens a uniformly bright sphere, of 30 millimetres diameter, is provisionally assumed as the illuminant, and a correction, taking actual conditions into account, will afterwards be made. The plan previously followed by the Author [1] was to calculate the divergences at exit in any plane of the generating section, and perpendicular to that plane for cones of light from the sphere incident at the innermost and outermost points of the inner side of each profile; to consider the means of these pairs of divergences as the means for the respective zones; and thence, taking into account the quantities of light falling on each zone, to determine the mean divergences of each complete lens in the two planes specified. In the case considered, the divergences of cones of light incident at the middle point of each profile have in addition been calculated; and the means of the divergences at each succeeding pair of points have been taken as the mean divergences for the portions of light received by the corresponding included zones. The pencils of light followed through the lenses have thus been those (Fig. 4, Plate 5) incident at points *a*, *b*, *c*, *d*, *e*, *f*, *g* on the equiangular lens, at points *h*, *i*, *j*, *k*, *l*, *m*, *g* on the plane lens, and at points *n*, *o*, *p*, *q*, *r*, *s*, *g* on the spherical lens. For the two extreme ex-focal rays from opposite sides of the spherical illuminant in a plane perpendicular to that of the generating section incident at any of these points, the conditions are identical; and these rays emerge from the outer face of the lens, diverging from the central ray at angles equal to the angles of convergence towards it at the inner face.[2] For the two extreme opposite ex-focal rays incident at any point in a plane of the generating section, the conditions are not the same (save only at the axis of the central lens), so that these rays at emergence do not diverge by equal amounts from the central ray, as will appear in Table II.

Aberration.—Column 3 of the Table shows how the middle focal ray incident on each profile emerges from the lens without being

[1] Minutes of Proceedings Inst. C.E., vol. cxi. p. 296.
[2] *Ibid*, vol. cxi. p. 319.

brought to parallelism with the axis of the lens; how this aberration diminishes on passing from the central to the outer elements of each lens; and how it is practically the same in equi-

TABLE II.

1		2	3	4	5	6	7	8	9
Title of Element.		Incli-nation of Focal Ray to Axis at Inci-dence.	Incli-nation of Focal Ray to Axis at Emer-gence.	Internal Con-vergence of Extreme Ex-focal Rays.	Divergence at Emergence of Extreme Ex-focal Rays in Planes of Gene-rating Section.			Mean Divergence at Emergence.	
					From the Axis.	Towards the Axis.	Total.	In Planes of Gene-rating Section.	Perpen-dicular to Gene-rating Section.
		° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
Equiangular	E – 1	0 0	0 0	7 21	3 31	3 31	7 2	7 0½	7 8½
		7 58	0 26½	7 15	3 53½	3 5½	6 59	6 56½	7 6½
		15 54	0 0	6 58	3 24	3 30	6 54		
	E – 2	15 54	0 0	6 58	3 24	3 30	6 54	6 39½	6 49
		20 42	0 22	6 40	3 31	2 54	6 25	6 21	6 30½
		25 30	0 0	6 21	3 4	3 13	6 17		
	E – 3	25 30	0 0	6 21	3 4	3 13	6 17	6 5¼	6 14
		28 24	0 9½	6 7	3 1½	2 52	5 53½	5 51¼	6 0½
		31 18	0 0	5 52	2 50	2 59	5 49		
Plane	P – 1	0 0	0 0	6 52	3 16	3 16	6 32	6 33½	6 40
		7 58	0 26	6 48	3 42½	2 52½	6 35	6 44½	6 42
		15 55	0 0	6 36	3 22	3 32	6 54		
	P – 2	15 55	0 0	6 36	3 22	3 32	6 54	6 48¼	6 31
		20 42	0 22	6 26	3 40	3 2½	6 42½	6 52½	6 19
		25 29	0 0	6 12	3 25	3 37½	7 2½		
	P – 3	25 29	0 0	6 12	3 25	3 37½	7 2½	6 54¾	6 7½
		28 24	0 11	6 3	3 28	3 19	6 47	6 54¼	5 57½
		31 18	0 0	5 52	3 23	3 38½	7 1½		
Spherical	S – 1	0 0	0 0	5 52	2 44	2 44	5 28	5 36	5 40
		7 58	1 0½	5 52	3 52	1 52	5 44	6 20½	5 52
		15 53	0 0	5 52	3 24	3 33	6 57		
	S – 2	15 53	0 0	5 52	3 24	3 33	6 57	7 12¼	5 52
		20 42	0 39	5 52	4 17	3 10½	7 27½	8 32¾	5 52
		25 29	0 0	5 52	4 31	5 7	9 38		
	S – 3	25 29	0 0	5 52	4 31	5 7	9 38	9 57½	5 52
		28 24	0 16	5 52	5 2	5 15	10 17	11 36	5 52
		31 18	0 0	5 52	5 40	7 15	12 55		

angular and plane lenses, and distinctly greater in the spherical lens.

Internal Convergence.—From column 4 it is seen how the angle

of internal convergence varies through the widest range for the equiangular lens, diminishing from a unit angle of 7° 21′ to a minimum of 5° 52′; how it varies through a smaller range for the plane lens, between a unit angle of 6° 52′ and the same minimum of 5° 52′; and how for the spherical lens it is constant and equal to the minimum for all three lenses, which is the angle of convergence at *g* (Fig. 4, Plate 5), where the focal distance is the same for all three lenses and equal to the internal radius of the spherical lens.

Comparing columns 5 and 6, an apparent discrepancy is observed; the figures in column 6 being greater than the corresponding figures in column 5 in all cases for limiting rays, but less for middle rays. This is explained by the figures of column 3 showing the aberrations of middle focal rays, and if these aberrations be deducted from the corresponding figures of column 5 and added to those of column 6, it will be found that the divergences from the axis counted from the direction of middle incident rays at emergence, are greater than the divergences towards the axis counted similarly, just as in the case of limiting rays.

Divergence at Emergence.—Column 7, relating to planes of the generating sections, shows a wider range of divergence for the equiangular lens than for the plane lens, viz., 7° 2′ to 5° 49′ against 7° 2½′ to 6° 32′, and the widest range for the spherical lens, viz., 12° 55′ to 5° 28′. Column 8 gives the arithmetical means of divergences at the limits of inner and outer subdivisions of the elements, which are, with sufficient approximation, the means for these subdivisions. Column 9 gives the arithmetical means of the internal convergences of column 4, except in the case of the inner subdivision of central lenses, since the divergence at emergence perpendicular to the generating section at the centre of each central lens is the same as the corresponding divergence in the plane of the generating section. Hence, in determining the mean divergence in question for the inner subdivision of E – 1, for example, the mean of 7° 2 and 7° 15′ has been taken instead of that of 7° 21′ and 7° 15′, and similarly for P – 1 and S – 1. In other cases of column 9 the external divergences are considered to be equal to the internal convergences.

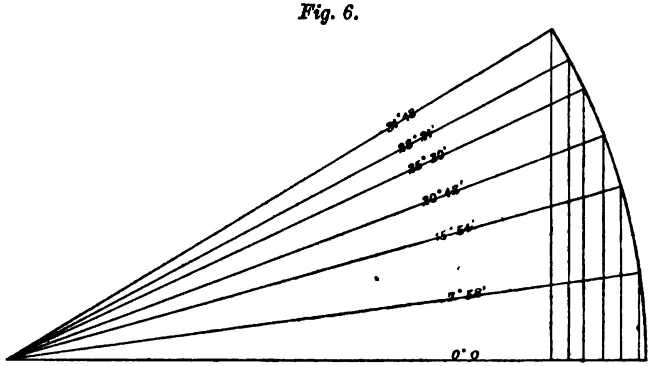
Condensing Action Peculiar to the Equiangular Lens.—Comparison of columns 4 and 7 shows that, whilst all three types of lens condense the internally convergent cones at the centre and middle of central lenses in planes of the generating section, the equiangular type alone condenses internally convergent cones at all other

points considered in such planes—the other two types producing at these points what may be called achromatic dispersion.

Range of Divergences.—A general survey of columns 8 and 9 shows the relative merits of the three forms of lens in respect of the degree to which they approach the ideal of uniform divergence throughout. The mean divergence ranges in the equiangular lens between 5° 51¼′ and 7° 8½′, in the plane lens between 5° 57½′ and 6° 54½′, and in the spherical lens between 5° 36′ and 11° 36′. The difference between the minimum and maximum mean divergences is thus respectively 1° 17¼′, 0° 57′ and 6° 0′.

The passage from the mean divergences of columns 8 and 9, Table II, to those which belong to each of the several elements and to each of the entire lenses will be readily followed with the help of Table III. The figures in columns 2 and 3 of this Table are simply those of columns 8 and 9 of Table II expressed

Fig. 6.



in minutes. Column 4 gives the heights of the spherical zones (on a sphere of radius 1) of light falling on elements 1, 2, 3, of the three lenses and on their inner and outer subdivisions, the limiting angles of the subdivisions being shown in *Fig. 6.* The heights of these zones are proportional to their area, and are equal to the differences of the cosines of the lower and upper limiting inclinations, cos 0° − cos 7° 58′ being = 0·00965, and so on.

Relative powers for the assumed Illuminant, neglecting losses at Transmission through the Lenses.—Supposing the illuminant to be a uniformly bright sphere, such as a spherical shell of incandescent platinum, of the assumed radius of 15 millimetres, and neglecting losses, the relative powers of the lenses would be inversely as the squares of the general mean divergences, or, which is the same

TABLE III.

1	2	3	4	5	6	7
Title of Element.	Mean Divergence in Minutes in ∥ Planes of a Generating Section.	Mean Divergence in Minutes in ⊥ Planes of a Generating Section.	Height of Zone on Sphere of Unit Radius.	Product of Columns 2, 3 and 4.	Mean Divergence per Element all Round.	Mean Divergence all Round for the Entire Lens.
—	d	δ	p	$d\,\delta\,p$	$\sqrt{\frac{\Sigma\,d\,\delta\,p}{\Sigma\,p}}$	—
E – 1 Inner Part	420·50	428·50	0·00965	1,738·8		
E – 1 Outer Part	416·50	426·50	0·02861	5,082·3	422·23' = 7° 2·23'	
E – 1 Totals .	..	..	0·03826	6,821·1		
E – 2 Inner .	399·50	409·00	0·02630	4,297·3		
E – 2 Outer .	381·00	390·50	0·03285	4,887·5	394' = 6° 34'	$\sqrt{\frac{22,329\cdot4}{0\cdot14554}}$ = 391·7' = 6° 31·7'
E – 2 Totals .	..	..	0·05915	9,184·8		
E – 3 Inner .	365·25	374·00	0·02294	3,133·7		
E – 3 Outer .	351·25	360·50	0·02519	3,189·8	362·47' = 6° 2·5'	
E – 3 Totals .	..	..	0·04813	6,323·5		
Grand totals .	..	..	0·14554	22,329·4		
P – 1 Inner .	393·50	400·00	0·00965	1,518·9		
P – 1 Outer .	404·50	402·00	0·02861	4,652·3	401·62' = 6° 41·62'	
P – 1 Totals .	..	..	0·03826	6,171·2		
P – 2 Inner .	408·25	391·00	0·02630	4,198·3		
P – 2 Outer .	412·50	379·00	0·03285	5,135·7	397·25' = 6° 37·25'	$\sqrt{\frac{22,732\cdot2}{0\cdot14554}}$ = 395·2' = 6° 35·2'
P – 2 Totals .	..	..	0·05915	9,334·0		
P – 3 Inner .	414·75	367·50	0·02294	3,496·5		
P – 3 Outer .	414·25	357·50	0·02519	3,730·5	387·5' = 6° 27·5'	
P – 3 Totals .	..	..	0·04813	7,227·0		
Grand totals .	..	..	0·14554	22,732·2		
S – 1 Inner .	336·00	340·00	0·00965	1,102·4		
S – 1 Outer .	380·50	352·00	0·02861	3,832·0	359·12' = 5° 59·12'	
S – 1 Totals .	..	..	0·03826	4,934·4		
S – 2 Inner .	432·25	352·00	0·02630	4,001·7		
S – 2 Outer .	512·75	352·00	0·03285	5,929·1	409·75' = 6° 49·75'	$\sqrt{\frac{25,861\cdot2}{0\cdot14554}}$ = 421·54' = 7° 1·54'
S – 2 Totals .	..	..	0·05915	9,930·8		
S – 3 Inner .	597·50	352·00	0·02294	4,824·7		
S – 3 Outer .	696·00	352·00	0·02519	6,171·3	478' = 7° 58'	
S – 3 Totals .	..	..	0·04813	10,996·0		
Grand totals .	..	..	0·14554	25,861·2		

thing, as the products of the maximum and minimum mean divergences. Thus

$$\frac{\text{power of equiangular}}{\text{power of spherical}} = \left(\frac{421 \cdot 54}{391 \cdot 7}\right)^2 = 1 \cdot 159,$$

or the equiangular would be 15·9 per cent. better than the spherical; and

$$\frac{\text{power of plane}}{\text{power of spherical}} = \left(\frac{421 \cdot 54}{395 \cdot 2}\right)^2 = 1 \cdot 139,$$

or the plane would be 13·9 per cent. better than the spherical; and

$$\frac{\text{power of equiangular}}{\text{power of plane}} = \left(\frac{395 \cdot 2}{391 \cdot 7}\right) = 1 \cdot 018,$$

or the equiangular would be 1·8 per cent. better than the plane. Similarly the powers of E − 1, P − 1, and S − 1 might be compared by comparing the inverse ratios of the squares of their general mean divergences (Column 6, Table III) and likewise the powers of the respective second and third elements.

In the Author's previous Paper [1] account was taken not only of divergence of emitted light, but also of losses by superficial reflection, absorption and chromatic dispersion, and of cost; and although variations of intensity and of apparent surface of actual illuminants above and below the focal plane were not allowed for, the opinion was expressed that the omission of these two items, whilst causing slight errors in the relative powers, would not cause errors so great as to put them in a wrong order. It is now proposed to take the whole of these influences into account in a more exact manner.

General considerations on Divergences of Lighthouse-lights: true and erroneous assumptions.—Before doing so, it may be well to consider some points in connection with the divergences of beams of light issuing from lighthouse lenses. For the usual oil, gas and alternating-current electric-arc illuminants, and for lenses extending no more than 32° above and below the focal plane, the divergences resulting from the forms of the lenses constitute the chief element on which their relative powers depend. This holds good even more for lenses confined to about 20° on each side of the focal plane, since the decrease of intensity of the illuminants is less appreciable within these limits. Beyond certain angles, above and below the focal plane, which vary for different burners, the fall of intensity

[1] Minutes of Proceedings Inst. C.E., vol. cxi. p. 296.

becomes more and more serious, and the intensity of the illuminant becomes a more important influence than the divergence due to the lens. Practically, it is for some purposes necessary to consider the combination of lens and actual burner—or the actual lighthouse-light; but it is by no means useless to consider the condensing or dispersing action of lenses independently of the burner, and in so far as it depends on the form of the lens itself. This action is best exposed by assuming an illuminant of constant dimensions and invariable form as seen from any point of a lens. The only form which answers to this condition is the sphere.

Until 1893, it was generally assumed that the convergent pencil of light falling from the illuminant on any point of a lens, was emitted from it as a divergent pencil such that angles of external divergence were all equal to corresponding angles of internal convergence. Had the assumption that the sine of the angle of divergence at any point is equal to the radius of the flame divided by its focal distance been correct, the extent of calculation on which the Author's previous method of determining the relative powers of lenses was based would have been superfluous. That they were in reality indispensable will appear from a comparison of the relative powers which follow from the erroneous assumption, with the true relative powers for the assumed illuminant, in the case of equiangular, plane and spherical lenses. Column 4 of Table II shows the angles of internal convergence at the points considered, which, on this assumption, represent also the corresponding angles of divergence in all directions. The general mean divergences of each of the entire lenses being worked out as before on this assumption, they are found to be 6° 37′, 6° 22½′ and 5° 52′ for equiangular, plane and spherical lenses respectively. The relative powers being inversely as the squares of these divergences, their order is therefore on this assumption reversed.

Graphic Illustration of Lenticular Strains.—Fig. 5, Plate 5, shows a partial elevation of the lenses of Fig. 4. The same figure illustrates the manner in which the images of the assumed spherical illuminant, produced by the lenses on screens distant 250 millimetres from the surfaces on their outer faces, from which the pencils of light converging internally on the points considered diverge, would be strained. On passing from the centre of the lens outwards, the equiangular lens causes a slight compressive strain, the plane lens a sensible tensile strain, and the spherical lens a conspicuous tensile strain of the emergent cones of light in every plane of the generating section. In each case the image suffers no strain perpendicular to planes of the generating section, but

decreases in breadth as the focal distance of the point of the lens considered increases, the external divergence being equal to the internal convergence. At the centre of all three lenses, however, and no doubt in a diminishing degree at other positions near the centre, the emergent cone of light suffers a compressive strain all round. *Figs. 7, 8* and *9* show maximum and minimum images in the case of equiangular, plane and spherical lenses respectively. Sections of pencils from the centre of the bull's-eye are styled a, from outermost points of the lenses ω. These figures, as well as Fig. 5, Plate 5, and columns 8 and 9 of Table II, show the plane lens to possess a

Fig. 7.

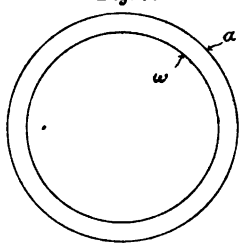


Fig. 8.

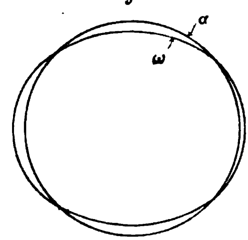
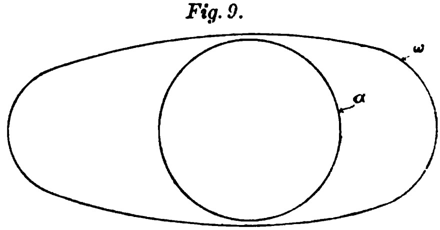


Fig. 9.

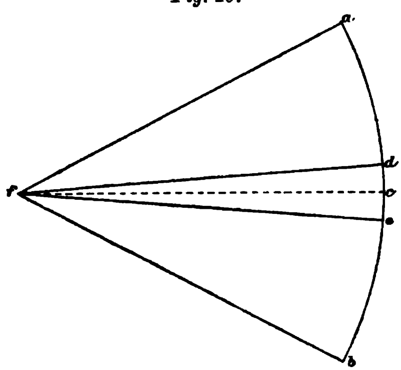


smaller range from maximum to minimum divergence, than either the equiangular lens or the spherical lens.

Pure factors of Lenses.—Circular surfaces equal to the elliptical surfaces of the images may be supposed to stand for the latter without change of the luminous intensity. And this is the same as the substitution of equivalent right circular cones for the actual strained emergent cones of light. Column 6 of Table III gives the angles of such equivalent cones for the separate elements, and column 7 the angles of such cones for the entire lenses. If afb, *Fig. 10*, represent the angle subtended by a lens, and dfe the mean angle of divergence of the emergent beam, the effect produced by the lens is equivalent to the condensation of a cone of light afb into a cone of light dfe. Describing with radius fa an arc adc, and supposing the arc ac to generate a spherical zone ab

by rotation about fc, dc generating similarly a smaller zone de, the condensation effected by the lens is measured by the ratio $\frac{\text{surface of zone } ab}{\text{surface of zone } de}$, or by the equivalent ratio $\frac{1 - \cos afc}{1 - \cos dfc}$. This formula gives a quotient which is the factor of the lens for the given illuminant, neglecting losses at passage through the lens. The practical factor for any given illuminant may be derived from this factor by modifying it, so as to take into account losses at passage through the lens and variations of mean intrinsic brightness of the illuminant above and below the focal plane. Whatever portion of the sphere round the illuminant be occupied by a lens, and whatever be the form of the lens, it is always easy to find, on a sphere of unit radius, an equivalent spherical zone; and whatever the divergences of the cones of light issuing from the lens, it is

Fig. 10.



always easy to find a single right circular cone, equivalent to the mean of these cones, which cuts out a determinate zone on the sphere of unit radius; and the surface of the former zone, divided by the surface of the latter, gives the pure factor of the lens. If a lenticular ring such as E – 2, Fig. 4, Plate 5, be dealt with separately, then the surface on a sphere of unit radius which it occupies is proportional to $\cos c\mathrm{F}a - \cos e\mathrm{F}a$, and its pure factor is $\frac{\cos c\mathrm{F}a - \cos e\mathrm{F}a}{1 - \cos \frac{\text{mean divergence}}{2}}$. If the separate pure factor for $\frac{1}{6}$ of E – 2 be required it is $\frac{1}{6}$ of that just given. The possibility of thus dealing with separate lenticular rings, or with segments of rings, is very important; since it allows varying losses and varying intrinsic intensities at different inclinations to be taken

into account with any required degree of exactitude. If the emergent cones of light from lenses with uniformly bright spherical illuminants were equal and similar to the corresponding internal convergent cones for all points of internal incidence, or if, in other words, the internally incident convergent cones emerged unstrained and merely with their axes brought to parallelism, then the lens factor would be

$$\frac{\text{spherical surface subtended by lens at focus}}{\text{mean spherical surface subtended by illuminant at all points of lens}}$$

It may be convenient to call the factors obtained for uniformly bright spherical illuminants, neglecting losses at passage through the lens, pure factors.

Returning to the three lenses, Fig. 4, Plate 5, for each of which the semi-angle subtended, $g\,F\,a$, is 31° 18′, and for which the semi-angles of equivalent right cones of mean divergence are (column 7, Table III) 3° 15·85′, 3° 17·6′ and 3° 30·77′, the pure factors are,—for the equiangular lens $\frac{1 - \cos 31° \; 18'}{1 - \cos 3° \; 15 \cdot 85'}$, = 89·718, 88·126 for the plane, and 77·46 for the spherical lenses; and these numbers are as 115·82, 113·77 and 100, or practically as the inverse squares of the divergences given in column 7 of Table III, namely, 115·9, 113·9 and 100.

Passage from Pure to Practical Factors of Lenses.—In comparing the powers of different lighthouse-lights, it is not sufficient to allow for loss by superficial reflection, dispersion or fall of intrinsic brightness in the illuminant, by adding these losses from element to element and taking the mean loss over each entire lens, and then by proportionately diminishing the lens factors. Losses from these causes may, however, be taken into account with any desired degree of accuracy by subdividing the entire lenses into small parts, and applying to each of these the corresponding losses; determining in fact the practical factor corresponding with each part, and then summing the separate practical factors to obtain the total factor. It will be sufficiently accurate in the present uncertainty of some of the data, to consider separately the several elements of the lenses of Fig. 4, Plate 5. Further, although the special divergence due to chromatic dispersion must be taken into account for absolute accuracy, it will be omitted here, because for lenses confined to 31° from the axis, it is not an important element; and further, in the absence of certain data concerning the relative penetrating-power of different parts of the spectrum, and of certain data concerning burners,

it is hardly worth while now to complicate matters on account of it.

Variation of Mean Intrinsic Brightness of the Illuminant.—In Figs. 11, Plate 5, is shown a half-size vertical elevation of the one-wick burner-flame as given by Mr. Allard;[1] to the right of it views of the same flame as seen from the upper middle points of the three elements of any of the lenses compared in a vertical focal plane; and to the left of it similar views from below the focal plane. In each view a dotted circle represents the provisionally assumed spherical illuminant of 15 millimetres radius. The space between the burner-top and the flame in the vertical elevation corresponds with non-luminous flame, and the upper spikes of flame are omitted. It will be observed that, although the excess of actual over assumed flame-area increases as the point of view rises above the focal plane, the mean intrinsic brightness over the added area can hardly be equal to the mean intrinsic brightness of the flame as viewed from the centre of the lens, since there is but one layer of flame radiating from the greater part of the added flame-area. Not only so, but, as the dotted semi-ellipses at the foot, and the lower semi-ellipses at the top, of the flame show, the central part of the flame, where double layers of flame radiate, has been more and more reduced; so that it would be a mistake to assume for the single-wick burner that the mean intrinsic brightness varies exactly in inverse proportion to the visible area of flame. Further, the portions of flame-area which, from being of double layer in the horizontal plane, become of single layer when viewed from higher points of the lens, are such as send their reduced light either above the horizon or far inshore; while the horizon and the greater part of the illuminated sea within it continue to receive light from double layers of flame. In the case of the one-wick lamp, matters are somewhat similar below the focal plane, but the rim of the burner cuts out a little light at the middle of the second lenticular zone, and more at the middle of the third zone; while the opaque central button generally used is more obstructive than above the focal plane, since the increased flame-area belongs mainly to the part of the flame behind the button. It seems not unreasonable in the circumstances to suppose, in the absence of results of direct photometrical measurements, that the effective flame-area remains unaltered over the vertical angle of the lenses considered, but that the total intensity, and therefore also on

[1] "Intensité et Portée des Phares," Plate VIII.

this supposition the mean intrinsic brightness, declines with increased removal from the focal plane somewhat as the figures given by Mr. Allard for a four-wick flame indicate. As Figs. 11 show, moreover, in this particular case, the area of the assumed spherical illuminant does not differ much from the actual visible areas of flame, so that the powers found for the assumed flame will not differ much from the actual powers. A more systematic method of determining mean intrinsic brightness at different inclinations will be followed in connection with the six-wick burner; for which it may be assumed to vary in the same way as for the four-wick burner—direct photometric measurements of total intensity at different inclinations having been made on the latter only.

Calculation of mean Total Intensities of Light falling on each Lenticular Zone.—Fig. 12, Plate 5, shows Mr. Allard's curve of intensities, to which reference has been made. In order to make this calculation both accurate and simple, it suffices to determine the circular line which divides the surface of each zone into two spherically equal zones; to take any number, say 16, equidistant points on it; to measure the vertical inclination above or below the focal plane of the focal ray through each of these points; to observe from the curve of Fig. 12, the intensity at each of these inclinations; and to divide the sum of these intensities by their number. In the present case the curves of intensity above and below the focal plane have been drawn to common abscissæ; and a third curve, representing the mean of the intensities above and below the focal plane at each inclination, has been drawn.

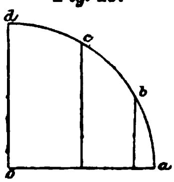
Instead of drawing the circle referred to, which spherically bisects the inner surface of each zone, it is simpler in practice to determine the angular inclination to the axis of any focal ray falling on such a circle, and then to draw a front view of the circle which the end of this focal ray describes on a sphere of unit radius as the ray makes one revolution round the axis, generating a conical surface. Consider, for example, any one of the elements E – 1, P – 1, or S – 1. The inner limiting angle is 0° and the outer limiting angle is 15° 54′. The inclination to the axis of the focal ray, which bisects the spherical zone of light falling on the element, is—

$$\cos^{-1}\left\{\frac{\cos 0^\circ + \cos 15^\circ\ 54'}{2}\right\} = 11^\circ\ 14'.$$

Suppose *o*, *Fig. 13*, to be the projection on the plane of the paper

of the axis of a sphere of unit radius coinciding with the axis of the element. Since 11° 14' or 0·1948 will be the radius of the circle traced on the sphere of unit radius by the end of the ray or radius inclined 11° 14' to the axis whose projection is *o*. Taking the unit equal to 1 decimetre, draw a quadrant around *o* with a radius of 19·48 millimetres, and mark on it equidistant points *a*, *b*, *c*, *d*, *Fig. 13*. From *b*, *c*, *d*, drop perpendiculars on *o a*. These perpendiculars are then the natural sines of the vertical inclinations of corresponding focal rays passing through the circles which spherically bisect the elements E – 1, P – 1, and S – 1. The natural sines are at once read off on a double-decimetre scale applied to the perpendiculars from *a*, *b*, *c*, *d* on *o a*, and the corresponding angles of inclination are given by a Table of natural sines. They are 0°, 5° 34', 8° 34' and 11° 14'. The corresponding means of the intensities above and below the focal plane are by Fig. 12, Plate 5, 0·994, 0·988, and 0·984. Taking the sum of the extreme and twice the intermediate terms and dividing by 6, the mean intensity for each of the entire elements No. 1 is found to be 0·991. Similarly, mean intensities of 0·9733 and 0·949 are found for elements 2 and 3 respectively. These, then, are the mean total intensities of light falling on the several elements, the total intensity in the horizontal plane being supposed equal to 1.

Fig. 13.



Pure Factors of Individual Elements.—Resorting now to the method of calculating the pure factors of the elements described, and referring to column 6 of Table III for the mean divergences of the several elements, the pure factor of E – 1 is found to be—

$$\frac{1 - \cos 15^\circ\ 54'}{1 - \cos 3^\circ\ 31 \cdot 11'} = \frac{0 \cdot 0382587}{0 \cdot 0018848} = 20 \cdot 299,$$

that of E – 2,

$$\frac{\cos 15^\circ\ 54' - \cos 25^\circ\ 30'}{1 - \cos 3^\circ\ 17'} = 36 \cdot 038,$$

and that of E – 3,

$$\frac{\cos 25^\circ\ 30' - \cos 31^\circ\ 18'}{1 - \cos 3^\circ\ 1 \cdot 3'} = 34 \cdot 14.$$

Similarly the pure factors of P – 1, P – 2, and P – 3 are 22·481, 35·328, and 30·459 respectively; and those of S – 1, S – 2, and S – 3 are 27·994, 33·296, and 19·974 respectively.

Table IV represents the method of reducing pure factors to actual factors.

TABLE IV.

1	2	3	4	5
Title of Element.	Pure Factor.	Coefficient of Transmission.	Mean Intensity for Horizontal Intensity = 1.	Actual Factor.
E − 1	20·299	0·8661	0·991	17·423
E − 2	36·038	0·8638	0·9733	30·301
E − 3	34·140	0·8579	0·949	27·795
Total . . .	90·477			75·519
P − 1	22·481	0·8661	0·991	19·296
P − 2	35·328	0·8627	0·9733	29·663
P − 3	30·459	0·8537	0·949	24·678
Total . . .	88·268			73·637
S − 1	27·994	0·8866	0·991	24·597
S − 2	33·296	0·8684	0·9733	28·143
S − 3	19·974	0·8178	0·949	15·501
Total . . .	81·264			68·241

The figures of column 5, except the totals, are the products of the corresponding figures of columns 2, 3 and 4. Comparison of the total pure factors with total actual factors shows that the order of the powers is not changed for the three types of lens, when allowance is made for losses at transmission and by fall of intensity.

The relative pure factors of the equiangular, plane and spherical lenses under review were deduced from Table III as 115·9, 113·9 and 100, while the relative pure factors deducible from the pure factors of Table IV are 111·38, 108·62 and 100. Consequently, the relative pure factors of the entire equiangular and plano-convex lenses calculated directly are respectively 4·09 per cent. and 4·86 per cent. higher than the relative pure factors obtained by summing the pure factors of the individual elements similarly calculated. This discrepancy, although practically inconsiderable, has to be explained and rectified. Until the cause has been demonstrated it will be advisable to take the mean of the pure factors found by the two modes of applying the method, as the probable true pure factor.

Mixed Spherical-plane, Spherical-equiangular and Plane-equiangular Lenses.—As already mentioned, the plan of calculating the factors of the separate elements of a lens and then taking their sum as the

factor of the entire lens has the merit of rendering it possible to take into account the advantages or disadvantages peculiar to each element in respect of each of its properties, which do not all vary in the same direction. In estimating the efficiency of mixed lenses, it will be best to accept provisionally as accurate the factors found for the separate elements which favour the equiangular and spherical types of lens, and to neglect the factors found directly for entire lenses which favour the plano-convex lens.

In Fig. 4, Plate 5, the middle ray falling on element E − 2 at *d* is inclined 20° 42′ to the axis. The perpendicular *dt* is drawn to the axis, and about the centre F with radius F *d* a circular arc *d u* is described. Then *g d u* may represent the inner side of the generating section of a mixed spherical-equiangular lens as proposed, and *g d t* that of a mixed plane-equiangular lens which it is of interest to compare with it. The corresponding mixed spherical-plane lens, as proposed, has for inner side *g k v*, where R *v* is an arc with centre F and radius F *k*. There are thus now three mixed lenses, namely *g k v* spherical-plane, *g d u* spherical-equiangular, and *g d t* plane-equiangular in contrast with the all-equiangular lens *g a*, the all-plane lens *g h*, and the all-spherical lens *g n*, all having the same maximum radius or horizontal focal length F *g*. For the reasons given, the assumed spherical illuminant, deprived only of its original quality of uniform brightness in all directions, may still stand for the actual flame of the one-wick burner of 30 millimetres diameter.

The all-spherical lens has been already considered. The principal focal length of the spherical-plane lens *g k v*[1] is F *v* = F *k* = 267·25 millimetres. The principal focal length of the spherical-equiangular lens *g d u* is F *u* = F *d* = 257·71 millimetres. And the principal focal length of the plane-equiangular lens *g d t* is F *t* = 241·22 millimetres. A little reflection will enable it to be seen that the actual factors of the spherical lenses *k v* and *d u* can be derived with an exactitude, which, if not absolute, is at least amply sufficient for practical purposes, from the actual factor of the spherical lens *q n*, by multiplying the latter by $\left(\frac{\mathrm{F}\,v}{\mathrm{F}\,n}\right)^2$ and by $\left(\frac{\mathrm{F}\,u}{\mathrm{F}\,n}\right)^2$ respectively; the actual factor of *p n* or S − 1 is found in Table IV to be 24·597. To obtain that of *q p* it is necessary to

[1] In practice, new profiles would be calculated for this and the other mixed lenses here designated by the inner side of their profiles, but this special calculation is not necessary for comparing their efficiencies.

return to Table II, which shows that the mean divergences in and perpendicular to any plane of the generating section through qp are 7° 12¼′ and 5° 52′ respectively, whence can be calculated a mean divergence all round of 6° 30′. Noting the limiting rays of qp in Table II, the pure factor is $\frac{\cos 15° 53' - \cos 20° 42'}{1 - \cos 3° 15'} = 16 \cdot 4$. Multiplying this again by 0·8743 and 0·9786, coefficients of transmission and intensity found in the same way as those of columns 3 and 4, Table VI, the actual factor of 14·034 is obtained. Adding this to 24·597, the actual factor of the spherical lens qn is found to be 38·631. The latter figure multiplied by $\left(\frac{Fv}{Fn}\right)^2$ or by $\left(\frac{267 \cdot 25}{292 \cdot 58}\right)^2$ becomes 32·231, the actual factor of spherical lens kv; and multiplied by $\left(\frac{Fu}{Fn}\right)^2$ or by $\left(\frac{257 \cdot 71}{292 \cdot 58}\right)^2$ it becomes 29·971, the actual factor of spherical lens du. The actual factor of the plane lens kj, as for the spherical lens qp, is 13·134, which, added to 19·296 (the actual factor of P – 1, see Table IV), gives 32·43 as the total actual factor of plane lens kh. The actual factor of plane lens dt is obtained by multiplying 32·43 by $\left(\frac{Ft}{Fh}\right)^2$, or by $\left(\frac{241 \cdot 22}{250}\right)^2$, and is 30·192.

The actual factor of plane lens lk could be found in the same way as that of spherical lens qp, but it can also be obtained by subtracting the actual factor of kj from that of lj or P – 2, and is (see Table IV) 29·663 – 13·134 = 16·529. The actual factor of the equiangular lens ed must be found in the same manner as that of qp. Thus from Table II the divergences in and perpendicular to planes of the generating section of the upper portion of E – 2 are seen to be 6° 21′ and 6° 30½′; hence the mean all-round divergence of 6° 26′ can be deduced. And the pure factor is

$$\frac{\cos 20° 42' - \cos 25° 30'}{1 - \cos 3° 13'} = 20 \cdot 856.$$

Multiplying this by 0·8623 and 0·9680, coefficients of transmission and of intensity, the practical factor 17·41 is obtained. Hence the practical factor of the plane lens gk is 16·529 + 24·678 (Table IV) = 41·207, and that of equiangular lens gd is 17·41 + 27·795 (Table IV) = 45·205. From the foregoing data, Table V is compiled, showing the actual factors of the six lenses under comparison.

TABLE V.

Lens.	Equiangular $g\,a$.	Plane-equiangular $g\,d\,t$.	Spherical-equiangular $g\,d\,u$.	Plane $g\,h$.	Spherical-plane $g\,k\,v$.	Spherical $g\,n$.
Actual factor	75·519	75·397	75·176	73·637	73·438	68·241
or as	110·67	110·49	110·16	107·91	107·61	100·0

A striking feature of this Table is the approximate equality of the relative powers of the first five types of lens, the extremes, 110·67 and 107·61, being within little more than 2½ per cent. of each other.

The agreement of pure and actual factors is closer the greater the focal length of the lenses compared, spherical aberration being reduced as the number of subdivisions of the subtended angle increases. With lenses of greater focal length also a four-wick burner, the only lighthouse oil-burner the variations of intensity of which above and below the focal plane have been directly measured and recorded, or one, such as a six-wick burner, the intensity and intrinsic brightness of which doubtless vary similarly, may be appropriately taken for the illuminant. Fig. 14, Plate 5, shows portions of a spherical lens and a plano-convex lens. Both lenses extend to 20° 48′ beyond the axis, and have the same maximum radius of 1,330 millimetres and five similarly-placed elements intercepting respectively equal spherical zones of light from the illuminant. The calculation of the powers of these lenses, with a six-wick burner as illuminant, is given in Table VI.

Mean Maximum and Minimum Divergences.—Columns 4, 10 and 15 give the calculated external divergences at three positions in each element in any plane of the generating section, and the means of these three divergences, given in column 18, are obtained by dividing the first plus twice the second plus the third by four. These are the mean maximum divergences. The external divergences perpendicular to all planes of the generating section are taken to be equal to the internal convergences of columns 3, 9 and 14; except at the centre of each lens, where they are equal to the external divergences $S-1$, column 4, and $P-1$, column 4. Column 19 gives the mean minimum divergences, found as those of column 18.

Range of Maximum and Minimum Divergences.—The Table allows the variations of the maximum and minimum divergences to be followed at each of the points considered, but the nature of

TABLE VI.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Inner Limiting Position.					Mean position of Element.						Outer Limiting Position.					Mean Divergence in Minutes.		
Title of Lens and Element.	Inclination of Focal Ray to Axis.	Internal Convergence.	External Divergence in Plane of Generating Section.	Portion of Divergence towards the Axis.	Portion of Divergence from the Axis.	Inclination of Focal Ray to Axis.	Aberration of Focal Ray from Axis.	Internal Convergence.	External Divergence in Plane of Generating Section.	Portion towards Axis.	Portion from Axis.	Inclination of Focal Ray to Axis.	Internal Convergence.	External Divergence in Plane of Generating Section.	Portion towards Axis.	Portion from Axis.	In Generating Section.	Perpendicular to Generating Section.	All Round.
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	′	′	′
S – 1	0 0	5 36	5 29·7	2 44·85	2 44·85	5 30	0 8	5 36	5 39·5	2 42·5	2 57	7 47	5 36	5 50	2 55	2 55	339·7	334·4	337·04
P – 1	0 0	6 0	5 54	2 57	2 57	5 30	0 3	5 58	5 57·3	2 56·3	3 1	7 47	5 56	5 59	3 1	2 58	356·9	356·5	356·7
S – 2	7 47	5 36	5 50	2 55	2 55	9 58	0 5	5 36	5 55·9	2 54·2	3 1·7	11 45	5 36	6 10·5	3 7	3 3·5	358·1	336·0	346·87
P – 2	7 47	5 56	5 59	3 1	2 58	9 58	0 2·6	5 54	5 57·6	2 58	2 59·6	11 45	5 52	6 1·5	3 2·5	2 59	358·9	354·0	356·44
S – 3	11 45	5 36	6 10·5	3 7	3 3·5	13 35	0 5	5 36	6 18·8	3 7·3	3 11·5	15 12	5 36	6 37	3 22	3 15	381·3	336·0	357·93
P – 3	11 45	5 52	6 1·5	3 2·5	2 59	13 35	0 3	5 49·6	6 0	2 59	3 1	15 12	5 47	6 3·8	3 4·5	2 59·3	361·1	349·5	355·25
S – 4	15 12	5 36	6 37	3 22	3 15	16 46	0 3·7	5 36	6 47·4	3 24	3 23·4	18 12	5 36	7 9·4	3 40	3 29·4	410·3	336·0	371·3
P – 4	15 12	5 47	6 3·8	3 4·5	2 59·3	16 46	0 1·4	5 44	6 1·3	3 1·3	3 0	18 12	5 41·6	6 6	3 6	3 0	363·2	344·2	353·57
S – 5	18 12	5 36	7 9·4	3 40	3 29·4	19 32	0 3	5 36	7 20·7	3 48	3 37·7	20 48	5 36	7 45	4 0	3 45	444·0	336·0	386·25
P – 5	18 12	5 41·6	6 6	3 6	3 0	19 32	0 1·3	5 39	6 4	3 3·8	3 0·2	20 48	5 36	6 7·4	3 7	3 0·4	365·3	338·9	352·26

these variations is most clearly and simply displayed in columns 18 and 19.

General mean Divergences.—Column 20 gives the geometrical mean of figures of columns 18 and 19, which is the mean divergence all round, or the angle of a right circular cone of emergent light equivalent to the mean of the actual strained cones of emergent light.

Pure Factors.—These factors are the quotients of spherical zones of light received by the several elements divided by the spherical zones of light emitted, the zones in either case being measured on a sphere of unit radius. Such zones being proportional to their heights, the quotients may be obtained by dividing the corresponding heights. Table VII illustrates the process.

TABLE VII.

Title of Element.	Height of Zone of Light Received on Sphere of Unit Radius.	Height of Zone of Light Emitted on Sphere of Unit Radius.	Pure Factor.
	° ′ ° ′	° ′	
S – 1	cos 0 – cos 7 47 = 0·0092127	1 – cos 2 48·52 = 0·0012013	7·669
S – 2	cos 7 47 – cos 11 45 = 0·0117418	1 – cos 2 53·43 = 0·0012722	9·229
S – 3	cos 11 45 – cos 15 12 = 0·0140290	1 – cos 2 58·96 = 0·0013547	10·356
S – 4	cos 15 12 – cos 18 12 = 0·0150444	1 – cos 3 5·65 = 0·0014578	10·320
S – 5	cos 18 12 – cos 20 48 = 0·0151464	1 – cos 3 13·12 = 0·0015775	9·602
			47·176
P – 1	.. .. .. 0·0092127	1 – cos 2 58·35 = 0·0013455	6·847
P – 2	.. .. .. 0·0117418	1 – cos 2 58·22 = 0·0013435	8·740
P – 3	.. .. .. 0·0140290	1 – cos 2 57·62 = 0·0013345	10·513
P – 4	.. .. .. 0·0150444	1 – cos 2 56·78 = 0·0013369	11·253
P – 5	.. .. .. 0·0151464	1 – cos 2 56·13 = 0·0013122	11·543
			48·896

The fourth column of the Table shows the relative efficiencies of the several elements of each type of lens in respect of divergence alone, and the totals show the relative efficiencies of the entire lenses in this respect alone.

Passage from Pure to Practical Factors.—The conversion of these pure factors into practical or actual factors is accomplished by allowing for losses by superficial reflections and by absorption in the lenses, and for variations of mean intrinsic brightness of the actual illuminant above and below the horizontal plane; these mean brightnesses or intensities being directly proportional to the total intensities and inversely proportional to the visible areas of flame. The latter can be easily determined by drawings for illuminants

of given dimensions. Any difference between the practical factors so estimated and the actual practical factors will be mainly attributable, provided that no mistakes of calculation have occurred, to imperfect construction or adjustment of the optical instruments, or to defects in the glass causing abnormal losses by absorption, for all which defects the constructor is responsible. The importance of being able to distinguish between the estimated and the actual factors will be readily recognised.

Coefficients of Transmission.—The losses by reflection being derived from Fresnel's formulas, and the absorption being taken as 0·03 per centimetre of glass traversed, as suggested by Mr. Allard, Table VIII explains itself.

TABLE VIII.

Title of Element.	Mean Angle of Incidence.	Mean Thickness of Glass Traversed.	Mean Angle of Emergence.	Refracted, r_1.	Passed, p.	Refracted, r_2.	Transmitted, $r_1 p r_2 = t$.
	° ′	Centimetres.	° ′				
S – 1 .	0 0	1·8	15 17	0·9687	0·946	0·9561	0·8762
S – 2 .	0 0	2·1	27 22	0·9687	0·937	0·9550	0·8668
S – 3 .	0 0	2·4	36 14	0·9687	0·928	0·9509	0·8548
S – 4 .	0 0	2·5	43 23	0·9687	0·925	0·9471	0·8486
S – 5 .	0 0	2·6	49 5	0·9687	0·922	0·9393	0·8389
P – 1 .	5 30	1·8	10 10	0·9561	0·946	0·9561	0·8648
P – 2 .	9 58	2·1	18 18	0·9561	0·937	0·9560	0·8564
P – 3 .	13 35	2·4	24 30	0·9561	0·928	0·9555	0·8478
P – 4 .	16 46	2·5	29 48	0·9560	0·925	0·9545	0·8441
P – 5 .	19 32	2·6	34 6	0·9559	0·922	0·9532	0·8401

Allowance for difference of size of actual and provisionally assumed spherical illuminant, and for variations of intensity and visible area of the former towards points of the lens above and below the focal plane.—Let I_0 be the total intensity of the actual six-wick flame in the horizontal plane and a_0 its visible area at the centre of the lens, then the mean intrinsic intensity in that direction is $\frac{I_0}{a_0}$. And if I_1 represents the mean total intensity of the same flame in the direction of all internal points of lenses S – 1 or P – 1, and a_1 the corresponding mean visible area, then the mean intrinsic intensity towards each of the bull's-eye lenses is $\frac{I_1}{a_1}$, and similarly $\frac{I_2}{a_2}$, $\frac{I_3}{a_3}$, $\frac{I_4}{a_4}$ and $\frac{I_5}{a_5}$ may represent the mean intrinsic intensities to-

wards elements 2, 3, 4 and 5 of the two lenses. Suppose further that the invariable visible area of the provisionally assumed spherical illuminant be represented by A. The divergences of Table VI have been calculated from A, and the pure factors of Table VII refer also to an illuminant of constant visible area A. To convert the pure factors, therefore, into the actual factors in respect of divergence, it suffices to multiply them by $\frac{A}{a_1}$, $\frac{A}{a_2}$, &c.—the divergent cones of emitted light being inversely proportional to the visible areas of the illuminant for any given focal length. The total intensity of the actual flame being variable in different directions, the mean total intensity towards each element can be represented by I_1, I_2, &c. Instead of counting I_0, the horizontal total intensity, in candles or carcels, let it be supposed equal to 1, so that I_1, I_2, &c., will with ordinary burners stand for fractions. Hence the allowances under consideration will be made by multiplying the pure factors of column 4, Table VIII, by factors $\frac{A}{a_1}$ I_1, $\frac{A}{a_2}$ I_2, &c. In the absence of actual photometric measurements of the varying intensities of the six-wick burner, it may be reasonably assumed that these vary as those of the four-wick burner, and also that the variations of visible area are likewise parallel in the two burners. Thus the factors $\frac{A}{a_1}$ I_1, &c., are equal for these two burners, and may now be determined from the data referring to the four-wick burner.

Fig. 12, Plate 5, gives Mr. Allard's curve of intensities for the four-wick burner. Figs. 15, Plate 5, give views of the four-wick flame as seen from points of a lens lying on lines inclined 0°, 10°, 20° 42′ and 28° 24, above and below the focal plane. Fig. 16, Plate 5, gives curves of areas of flame visible at different inclinations from the focal plane; a quadrant of the front view of the intersection on a sphere of unit radius of the conical shell which, from its apex at the focus, spherically bisects each optical zone, has been drawn, a decimetre being taken as unit. Four equidistant points, dividing the quadrant into three equal arcs, have been marked. The natural sines of the vertical angles of inclination of lines through these points are then given by the perpendiculars from them on the horizontal radius of the quadrant, and are read off directly with a double-decimetre scale. The corresponding angles are then found from a Table of natural sines. These angles are given in Table IX, and beside them the cor-

TABLE IX.

Bull's Eye.			No. 2.			No. 3.			No. 4.			No. 5.		
Vertical Incli-nation.	Total Intensity.	Visible Area.	Vertical Incli-nation.	Total Intensity.	Visible Area.	Vertical Incli-nation.	Total Intensity.	Visible Area.	Vertical Incli-nation.	Total Intensity.	Visible Area.	Vertical Incli-nation.	Total Intensity.	Visible Area.
° ′		Cm.	° ′		Cm.	° ′		Cm.	° ′		Cm.	° ′		Cm.
0 0	1·000	44·41	0 0	1·000	44·41	0 0	1·000	44·41	0 0	1·000	44·41	0 0	1·000	44·41
2 42	0 999 0·999	45·30 45·30	4 56	0·998 0·998	45·80 45·80	6 40	0·997 0·997	46·35 46·35	8 6	0·996 0·996	46·80 46·80	9 33	0·995 0·995	47·24 47·24
4 42	0·998 0·998	45·80 45·80	8 30	0·996 0·996	46·80 46·80	11 35	0·993 0·993	47·70 47·70	14 22	0·991 0·991	48·40 48·40	16 40	0·989 0·989	49·00 49·00
5 30	0·997	46·00	9 58	0·995	47·24	13 35	0·992	48·30	16 46	0·989	49·00	19 32	0·986	49·75
−0 0	1·000	44·41	0 0	1·000	44·41	0 0	1·000	44·41	0 0	1·000	44·41	0 0	1·000	44·41
−2 42	0·998 0·998	44·41 44·41	−4 56	0·995 0·995	44·20 44·20	− 6 40	0·991 0·991	44·00 44·00	− 8 6	0·987 0·987	43·80 43·80	− 9 33	0·981 0·981	43·52 43·52
−4 42	0·995 0·995	44·20 44·20	−8 30	0·985 0·985	43·80 43·80	−11 35	0·975 0·975	43·20 43·20	−14 22	0·963 0·963	42·20 42·20	−16 40	0·953 0·953	41·20 41·20
−5 30	0·993	44·10	−9 58	0·980	43·52	−13 35	0·968	42·50	−16 46	0·958	41·20	−19 32	0·937	39·50
Total	11·970	538·34	Total	11·923	540·78	Total	11·872	542·12	Total	11·816	541·42	Total	11·759	539·99
Mean	0·9975	44·86	Mean	0·9935	45·065	Mean	0·989	45·177	Mean	0·985	45·118	Mean	0·980	44·999

responding intensities from Fig. 12, and visible areas from Fig. 16. Angles below the focal plane are marked negative.

The lowest row of Table IX gives 0·9975, 0·9935, 0·989, 0·985 and 0·980 as the mean total intensities, I_1 &c., of the four-wick flame towards the respective elements of the lenses under consideration; and it also gives 44·86, &c., as the mean visible areas, a, &c., of the same flame turned towards these elements. Now the area A of the spherical illuminant corresponding to the four-wick flame is that of a circle of 9 centimetres diameter, or 63·62 square centimetres area. Hence $\frac{A}{a_1} = \frac{63 \cdot 62}{44 \cdot 86} = 1 \cdot 418$, and similarly $\frac{A}{a_2}$, $\frac{A}{a_3}$, $\frac{A}{a_4}$ and $\frac{A}{a_5}$ are respectively equal to 1·412, 1·408, 1·410 and 1·414.

Remembering that $\frac{A}{a_1}$ I_1, &c., are equal for six-wick and four-wick flames, all the component factors of the practical factors of the lenses of Fig. 14, Plate 5, with the six-wick burner as illuminant, have now been determined, and the latter are found by multiplying together the component factors as exhibited in Table X.

TABLE X.

Title of Element.	Pure Factor, $\frac{S}{s}$.	Coefficient of Transmission, $r_1 p r_2 = t$.	Mean Intensity Referred to Unit Intensity in Horizontal Plane, I_1, I_2, &c.	Ratio of Provisionally Assumed to Actual Flame-Area, $\frac{A}{a_1}$, $\frac{A}{a_2}$, &c.	Practical Factor, $\frac{S}{s} t I \frac{A}{a}$.
S − 1 .	7·669	0·8762	0·9975	1·418	9·501
S − 2 .	9·229	0·8668	0·9935	1·412	11·221
S − 3 .	10·356	0·8548	0·9890	1·408	12·320
S − 4 .	10·320	0·8486	0·9850	1·410	12·165
S − 5 .	9·602	0·8389	0·9800	1·414	11·161
Total	47·176	..	..	..	56·368
P − 1 .	6·847	0·8648	0·9975	1·418	8·355
P − 2 .	8·740	0·8564	0·9935	1·412	10·497
P − 3 .	10·513	0·8478	0·9890	1·408	12·413
P − 4 .	11·253	0·8441	0·9850	1·410	13·194
P − 5 .	11·543	0·8401	0·9800	1·414	13·437
Total	48·896	..	..	..	57·896

Relative positions of Plane and Spherical Lenses subtending the same angle and of equal power.—It is now a simple matter to determine the principal focal length of a plane lens equal in power to the

spherical lens of Fig. 14, Plate 5, the illuminant being the six-wick burner. Let d be the required focal length, then, the focal length of the plane lens shown being 1243·3 millimetres, the fact that the powers of similar lenses for the same illuminant are as the squares of their focal lengths, justifies the equation

$$d^2 = 1243 \cdot 3^2 \times \frac{56 \cdot 368}{57 \cdot 896},$$

whence $d = 1226 \cdot 8$; so that the principal focal length of a plane lens equal in power to the spherical lens of Fig. 14, Plate 5, is 16·5 millimetres shorter than that of the plane lens of the same figure. The inner side of this plane lens is shown by a dotted line.

FORMULATION OF THE METHOD EMPLOYED.

As may have been observed from Table XII, the method of calculating the practical factor of a given lens for a given illuminant, which has been exemplified in this Paper, may be expressed by the equation

$$F = \Sigma \frac{S\,A}{s\,a} I\,t \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

This equation may be translated into words thus :—

(a) The practical factor of a lens for a given illuminant is determined by subdividing the lens into any number of parts, whether entire elements or portions of elements, by determining the practical factor of each subdivision and taking the sum of the practical factors of all the subdivisions. (b) The practical factor of each subdivision is the product of the ratio of the solid angle of light received by it to the mean solid angle of light emitted by it from a provisionally assumed spherical illuminant, into the ratio of the constant visible area of the assumed illuminant to the mean visible area of the actual illuminant towards the subdivision, into the mean total intensity of the actual illuminant towards the subdivision, into the coefficient of transmission peculiar to the subdivision.

It might seem from a superficial view of the subject, that the provisional assumption of a spherical illuminant, and the subsequent introduction of a factor $\frac{A}{a}$ to restore the formula to correspondence with the actual illuminant is an unnecessary complication, but in reality this device simplifies the calculation. For to calculate the varying divergences at emergence in all planes at

a sufficient number of points of a lens, for the irregularly shaped visible areas of actual illuminants, would be a stupendous task in comparison with the calculation for a spherical illuminant, whilst it would not give increase of accuracy.

If the lens the factor of which is required is composed of entire zones, and a and β represent the inclinations to the axis of inner and outer limiting rays falling on any zone, and g represents the semi-angle of mean all-round divergence at emergence for the assumed spherical illuminant, then the formula may be put into the slightly more detailed form

$$F = \Sigma \frac{\cos a - \cos \beta}{1 - \cos \gamma} \frac{A}{a} I\, r_1\, p r_2 \quad . \quad . \quad . \quad (2)$$

Again, so long as $\frac{S}{s}$ is treated as a single factor, S and s may either stand for spherical zones on a sphere of unit radius or for quantities proportional to these zones. In separating the denominator s from the ratio $\frac{S}{s}$, it is necessary to bear in mind that s stands for the zone of a sphere of unit radius cut out by the right circular cone equivalent to the actually strained cone of divergent light from any element corresponding to the spherical illuminant. Now this zone s is directly proportional to A and inversely proportional to f^2 (f being the mean focal length of the element expressed in terms of the same unit as A and a) and to a factor q representing the condensing action peculiar to the type of lens considered. In fact

$$s = \frac{A}{f^2 q}.$$

Again I being the mean total intensity of the actual illuminant towards any element and a the mean visible flame-area towards the same element, $\frac{I}{a}$ is the mean intrinsic intensity of the illuminant towards that element and may be termed ϵ.

Substituting now $\frac{A}{f^2 q}$ for s and ϵ for $\frac{I}{a}$ in equation (1), a third form of the formula is obtained, namely:—

$$F = \Sigma\, S f^2 q \epsilon t \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If this equation be stated in words, the first part of the statement is the same as for equation (1) and the second becomes:—

(b) The practical factor of each subdivision is the product of the zone of a sphere of unit radius subtending the same solid angle as the subdivision, into the square of the mean focal length of the

subdivision, into the factor of condensation peculiar to the type of lens considered in the position of the subdivision, into the mean intrinsic brightness of the illuminant towards the subdivision, into the coefficient of transmission peculiar to the subdivision.

The factor q is the ratio of the mean visible area of an illuminant towards a portion of a lens of mean focal length f to the mean strained area of its image received on a screen at a distance f from that portion of the lens; or it is the ratio of the mean internal convergence all round at all points of a portion of a lens, to the corresponding mean external divergence all round for a given illuminant. This factor q is not the same at the centre of a lens as at parts of it remote from the centre. Suppose, however, that the mean value of q for the entire lenses of Figs. 3, Plate 5, be required, it is given by, first, determining the mean divergences all round of these lenses, on the (erroneous) assumption that external divergences are in all cases equal to the corresponding internal convergences; they are 6° 37′, 6° 22½′, and 5° 52′ for equiangular, plane and spherical lenses respectively; secondly, dividing these hypothetical divergences by those of column 7, Table III, and squaring the quotients. Thus q for the entire equiangular lens is $\left(\frac{6^\circ\ 37'}{6^\circ\ 31\cdot7'}\right)^2$, for the plane lens $\left(\frac{6^\circ\ 22\cdot5'}{6^\circ\ 35\cdot2'}\right)^2$, and for the spherical lens $\left(\frac{5^\circ\ 52'}{7^\circ\ 1\cdot54'}\right)^2$, or it is 1·028, 0·937, and 0·697 for these lenses respectively. In the case of catadioptric prisms of small section, q is practically equal to 1. This factor q is always calculable, being dependent on the law of refraction alone. It might probably be expressed in reference to any portion of a given type of lens as a function of the angular inclinations to the axis of rays falling on it. In the meantime it is fully taken into account by the calculation of mean all-round divergences at emergence as exhibited in Tables III and VI.

Axial Intensities and Useful Powers of Lighthouse-lights.—The manner in which the intrinsic brightness varies from point to point over the flame-areas of lighthouse illuminants, visible from different points all over a lens, has never yet been investigated, so that the above formula, in the first or third form given to it, seems to be as nearly complete and accurate as is possible with existing data. Although it does not necessarily give the axial intensity in terms of the total horizontal intensity of the illuminant, it does give the useful power of the lighthouse-light, which can be expressed in candles or carcels by multiplying by the number of these units contained in this assumed unit. This useful power is the mean power over the

whole portion of the beam of emitted light within the minimum cone of divergence. Besides giving the useful power, the formula will probably give with sufficient accuracy the relative powers of any number of lenses of different type subtending the same angles at the focus, and acting on the same illuminant, whether for axial or for any other intensity, the same part of the beams emitted from all these lenses, so long as this part lies within the minimum solid angle of divergence.

That this must be so appears probable from examination of any of the three forms of the formula. Suppose that the different lenses compared are cut into equal and similarly situated subdivisions. Then the only parts of the factors that are different in corresponding subdivisions of different lenses are $\frac{t}{s}$ in equation (1), $\frac{r_1 p r_2}{1 - \cos\gamma}$ in equation (2), and $f^2 q t$ in equation (3). Now suppose the axial intensities are required, and that the axial intensity is that which consists of the superposed divergent cones from all points of the lenses coming from circular flame-areas of one square centimetre surrounding the focal ray which goes to the sea-horizon through all points of the lenses. Suppose also, although this would appear to be rarely if ever true, that these circular flame-areas are the brightest parts of the whole flame-areas visible from all points of the lenses. Then the axial intensity given by the formula for any one entire lens will be greater than the useful intensity for that lens obtained from the flame-areas of the entire illuminant, because the part $\frac{\text{I}}{a}$, or ϵ of the factor for each subdivision, has become greater—the reduction of i for the special square centimetre having been less than the corresponding reduction of a. But there is no reason to suppose that the relative powers in respect of axial intensity of the different lenses differ materially from their relative useful powers, for $\frac{t}{s}$, $\frac{r_1 p r_2}{1 - \cos\gamma}$ and $f^2 q t$ remain as they were. The axial intensities must then apparently stand in the same order of merit as the useful powers; and the merit of any lens would appear to be greater, the less it has dispersed the light received by it outside the central cone of minimum divergence at emergence.

To an eye situated at the centre of a lens and regarding a multiple cylindric-wick oil-burner illuminant across the horizontal zone of maximum intensity, which it is customary to adjust for the sea-horizon, it would seem from a study of the horizontal section of this zone, Fig. 17, Plate 5, that the intensity, starting from a

maximum-minimum value P M at the middle of the zone, passes through a maximum-maximum value towards the border of the inner cylindrical flame, through a second maximum-value at the border of the second flame, and so on; until a final and minimum-maximum value is reached towards the border of the outermost cylindrical flame.

In Fig. 17 straight lines are drawn from C, the centre of a second order lens, through the centre of the flame O, and at close intervals through other parts to C T, which is tangential to the outside of the outermost flame. S P M 4 represents the varying depths of flame presented to the eye at C, to which depths the intensity would be roughly proportioned.

Power formula compared with other formulas.—So far as the Author is aware, only two other power formulas have been put forward. One of these is due to Mr. Allard, the other to Mr. Bourdelles. Mr. Allard's formula for revolving-light apparatus is dependent on his formula for fixed-light apparatus. The latter is:—

$$F = \frac{2}{3}\left(\frac{f}{\sqrt{d}}\right)^{1\cdot 15} \times \frac{3}{2}\frac{\phi}{2d} = \left(\frac{f}{\sqrt{d}}\right)^{1\cdot 15} \times \frac{\phi}{2a}.$$

Here f is the principal focal length of the lens, d the diameter of the burner or of the flame at the focal plane, ϕ the horizontal opening of the lens, and $2\,a$ the mean horizontal divergence of the emitted beam. F is the factor of the lens, and if I be the total horizontal intensity of the illuminant in carcels or candles, then the power in either of these units is F I. This refers to the power in the axis of the beam. One drawback in these formulas is that, if accurate, they can be so for one type of flame only.

Mr. Bourdelles has sought to construct a power formula of revolving-light combinations directly, as has been done in this Paper, and as was done for the relative powers in the Paper thereon, without making it depend in any way on the formula for fixed-light combinations. His formula is

$$F = \frac{2\,n\,w}{n\,180} f^2\,\epsilon\,k,$$

where $\frac{2\,n\,w}{n\,180}$ is the portion of a sphere of unit radius round the focus which would intercept the same light as the lens, f the focal length of an ideal spherical apparatus equivalent to the actual apparatus, ϵ the intrinsic mean spherical brightness of the burner, and k a coefficient to be determined experimentally, depending on the method of manufacture of the apparatus and on the absorption

of the glasses of which it is made, and practically constant for an apparatus of given type and order, but varying slightly with the order and the type.

Two objections, however, may be made to this formula:—

First, either k, which has to be determined experimentally, is intended to include factors which can be calculated from known laws and should therefore have been separated from the empirical part of the formula, or else the formula is incomplete. For the part $\frac{2\,n\,w}{n\,180} f^2 \epsilon$ does not allow for the condensing action peculiar to each type of lens, and this action follows in every case from the law of refraction. Again, this formula is not put into a form which allows of the varying coefficients of intrinsic brightness, and of transmission being applied to the portions of lenses to which they are specially applicable, these varying coefficients being all treated together as $\epsilon\, k$.

The formula is, however, in substantial agreement with that given by the Author. This is best seen when the latter is put in the form

$$F = \Sigma\, S f^2 q\, \epsilon\, t,$$

that of Mr. Bourdelles' being

$$F = \frac{2\,n\,w}{n\,180} f^2 \epsilon\, k.$$

Suppose now the sign Σ omitted from the former and the remainder $S f^2 q\, \epsilon\, t$ to stand for the power of the whole lens. Then S would be identical with $\frac{2\,n\,w}{n\,180}$, f^2 with f^2, ϵ with ϵ, and t would be included in k, so that the only differences would then be that the Author's formula allows for the straining action involved in the peculiar positive or negative condensing action of lenses by the factor q, whilst the other does not; and that, whilst the former gives the power for a lens constructed with all possible accuracy, the factor k in the latter appears to be intended to include a loss attributable to the average constructional defects.

In conclusion, it must be borne in mind that the determination by calculation of the power of a lighthouse-light requires that the intensity of the illuminant in all directions included by the optical apparatus be known, and that the dimensions of the illuminant be determinate.

The Paper is accompanied by two sheets of tracings, from which Plate 5 and the *Figs.* in the text have been prepared.

(*Paper No. 2643.*)

(*Abstract.*)

"The North Shore Water-Supply, Sydney, N.S.W."

By HAROLD ARTHUR BLOMFIELD, M. Inst. C.E.

THE populous suburbs of Sydney, collectively known as "North Shore," are separated from the city proper by the Parramatta river, which in this part of its course forms the harbour of Sydney. Until lately the only water-supply of the North Shore was obtained by a 9-inch pipe with flexible joints laid across the harbour. The new supply is a branch from the main aqueduct supplying the city of Sydney. This main aqueduct forms part of the Nepean scheme, which was designed by Mr. E. O. Moriarty, M. Inst. C.E., late Engineer-in-Chief of the Harbours and Rivers Department. It comprises a main storage reservoir and also a distributing reservoir of a capacity of 100,000,000 gallons at Potts Hill, and a canal and pipe-line designed to discharge 50,000,000 gallons per day. The pipe-line for North Shore commences at the Potts Hill reservoir with a 24-inch cast-iron pipe, reduced to 20 inches after some distance. It crosses the Parramatta river on a bridge carrying the Great Northern Railway, and is laid for a considerable distance alongside that railway. It discharges into a tank at Ryde, the length of pipe-line from Potts Hill being 13,700 yards and the fall 78 feet. The pipes on this line are of cast iron, $\frac{5}{8}$ inch and $\frac{3}{4}$ inch thick, except the portion, 1,000 feet long, on the railway bridge, which is of wrought iron, 0·3375 inch in thickness, flange-jointed. The contract price for laying the line of pipes was £3,781. Water was admitted to the tank in September 1890.

From the tank at Ryde, the water is pumped to service-reservoirs at Ryde Hill and Chatswood, respectively 234 and 370 feet above high water in Sydney harbour, the level of the pumps being 78 feet above high water. The tank is of concrete, of a cylindrical form, 140 feet in diameter and 24 feet from coping to floor. Its capacity, up to the overflow-level, 2 feet below coping, is 2,000,000 gallons. The concrete was made from Portland cement, sand, and

broken stone (trap rock), the cement and sand being well mixed before adding them to the stone. When finished, the walls and floor were rendered over. The foundation was in sandstone rock and was covered with 1 foot of concrete. The suction-pipe is fitted with two radiating arms by which the water can be drawn off at any required level. The contract for the tank was carried out for the sum of £5,888.

The engine- and boiler-house are of brick on a concrete foundation. The boilers are multitubular, four in number, 12 feet by 5 feet 6 inches. They are of the direct-acting, rotative, vertical, bucket-and-plunger type of 4 feet stroke. On a ten hours' test, they gave a duty of 120,000,000 foot-lbs. per 100 lbs. of coal consumed in the furnaces—the duty specified having been 90,000,000 lbs. The work done was measured by water pumped into the Chatswood service-reservoirs. The coal was of the best quality—obtained from Newcastle, N.S.W.

The rising main is of wrought-iron pipe (except special cast-iron lengths for bends, valves, &c.) 24¾ inches in diameter, of a thickness of 0·4 inch, 0·3375 inch or 0·275 inch, according to the pressure to which different parts of it are exposed. The iron was imported in plates of the proper length to form, when bent, a lap-jointed section of the pipe, and of a width of 4 feet 6 inches. Seven such plates having been punched, rolled, double-riveted along the lap, and butt-jointed and single-riveted along the transverse seams, formed a length of 31 feet 6 inches of pipe ready for laying. The transverse seams were covered with a welded band. The ends of the length were formed into a spigot and socket similar to those of cast-iron pipes; the spigot being made by welding up 8 inches of the lap at one end, while the socket was formed by shrinking and riveting on a welded band at the other end. The joints were caulked with special steam-caulking hammers. Each length was heated and dipped in a mixture of asphalt, tar and resin, and when nearly dry was sprinkled with sand. The pipes used amounted to a weight of 1,450 tons for a length of 6¼ miles. The price of the pipes delivered on the work was £25 10*s.* per ton. The lengths were jointed in the ordinary way with spun yarn gasket and lead, the only difference being that the caulking in the case of wrought-iron pipes was not as heavy as for cast-iron. In laying the pipes, care was taken to prepare the bed carefully throughout the trench to the true gradient for the whole length of pipe, so that no lifting or packing was required. The regulation depth from the surface to the top of the pipe was 2 feet. The rising main is taken across the Lane Cone river suspended

from two wire cables in two spans of 225 feet each. The three piers consist of cast-iron cylinders filled with concrete, the two shore piers resting on concrete bases and the river pier on a pair of cylinders, 5 feet in diameter, sunk 40 feet below the bed of the river. The cables are 1½ inch in diameter and are secured to anchorages of concrete let into the solid rock. The pipes are 35 feet above high water and are suspended by wrought-iron slings, 5 feet apart. The castings for this aqueduct were made in the colony, the ropes and slings being imported from England.

The service-reservoir at Ryde Hill is wholly above ground and is built of mild-steel plates on a concrete foundation. It is of a diameter of 100 feet, with a depth of water of 22 feet, and holds 1,000,000 gallons. The horizontal seams are lap-jointed and single riveted, the vertical seams being butt-jointed with double-riveted inside and outside covers. The plates are ¾ inch thick at the bottom reduced in ascending, the top row being $\frac{5}{16}$ inch thick. There are six tiers of plates having a depth of 4 feet and a length of about 14 feet. The connection between the plating and the concrete was made by a ring of sheet lead run in with bitumen, the lowest ring of plates being set in a cast-iron base-plate.[1] The lead ring was soldered at the joints. Dry sand was filled inside it through holes bored through the lead and then soldered over. When the reservoir had been filled and run dry again, no damage to the lead ring could be detected. The two reservoirs at Chatswood are similar to that at Ryde Hill, but are 10 feet higher and hold 1,500,000 gallons each. The contract price for the reservoirs was £16,040, all the steel being imported, but the planing, drilling, riveting, &c., being done by the contractor on the site.

The service-main from Ryde Hill to Hunter's Hill, 3 miles, is 15 inches in diameter; and that from Chatswood to North Sydney, 3½ miles, is 20 inches in diameter.

The whole of the works have now been vested in the Metropolitan Board of Water Supply and Sewerage, who have carried out the distribution system in connection with them. They were designed by Mr. C. W. Darley, M. Inst. C.E., Chief Engineer of the Harbour and Rivers Department, and the Author acted as Resident Engineer until the works were handed over to the Board.

The Paper is accompanied by four drawings and six photographs.

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[1] See "Notes on the Use, Construction, and Cost of Service Reservoirs in New South Wales," Journal of the Royal Society of N.S.W., Oct. 7, 1891.

(*Paper No. 2909.*)

"The Survey of the Delta of the Danube in 1894."

(Abstracted from the Report of Sir CHARLES HARTLEY, K.C.M.G., M. Inst. C.E.)

By LEVESON FRANCIS VERNON-HARCOURT, M.A., M. Inst. C.E.

FOUR surveys of the sea-coast of the delta of the Danube have been made previously to the one taken in July to October 1894, namely, in 1830, 1856, 1871, and 1883, from a comparison of which with each other, and with the recent survey, the changes that have occurred during these periods in the coast-line and foreshore at the mouths of the Danube have been ascertained. In the first Paper on the delta of the Danube, by Sir Charles Hartley, K.C.M.G., M. Inst. C.E., in 1862, besides a general description of the delta, reference is made to the changes which had taken place between 1830 and 1856;[1] and in his second Paper, in 1873, a full account is given of the changes in the sea-coast of the delta,[2] gathered from a comparison of the surveys of 1856 and 1871. In a third Paper, by Mr. C. H. L. Kühl, M. Inst. C.E., in 1888, describing the variations in depth in front of the Sulina mouth, a plan is added showing the changes which had occurred along the sea-coast of the delta between 1871 and 1883.[3] In a Report, with diagram and tables, addressed by Sir Charles Hartley in June 1887, to the European Commission of the Danube, reference is further made to changes that took place in the bed of the sea adjacent to the Sulina mouth during the previous twenty-nine years.[4]

The following particulars are taken, by special permission, from a Report in French, made by Sir Charles Hartley, in May 1895, to the European Commission of the Danube, on the changes since 1883, indicated by the survey of 1894; and the three *Figs.* in the text are reductions of the chart of the sea-coast of the delta accompanying the Report, showing the coast-lines and 1- and 5-fathom lines of 1883 and 1894, and also the fathom lines of 1856.

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[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 283.
[2] *Ibid*, vol. xxxvi. pp. 214 to 219, and plate 24.
[3] *Ibid*, vol. xci. pp. 329 to 333, plate 4.
[4] *Ibid*, vol. xci. pp. 334 to 339.

The survey of 1894 has been carried out in compliance with the wish expressed by Sir Charles Hartley at the close of his Report of November 1883, and urged again on the Commission in 1893, that a survey might be made every ten years of the sea-coast of the delta, to ascertain the changes in operation.

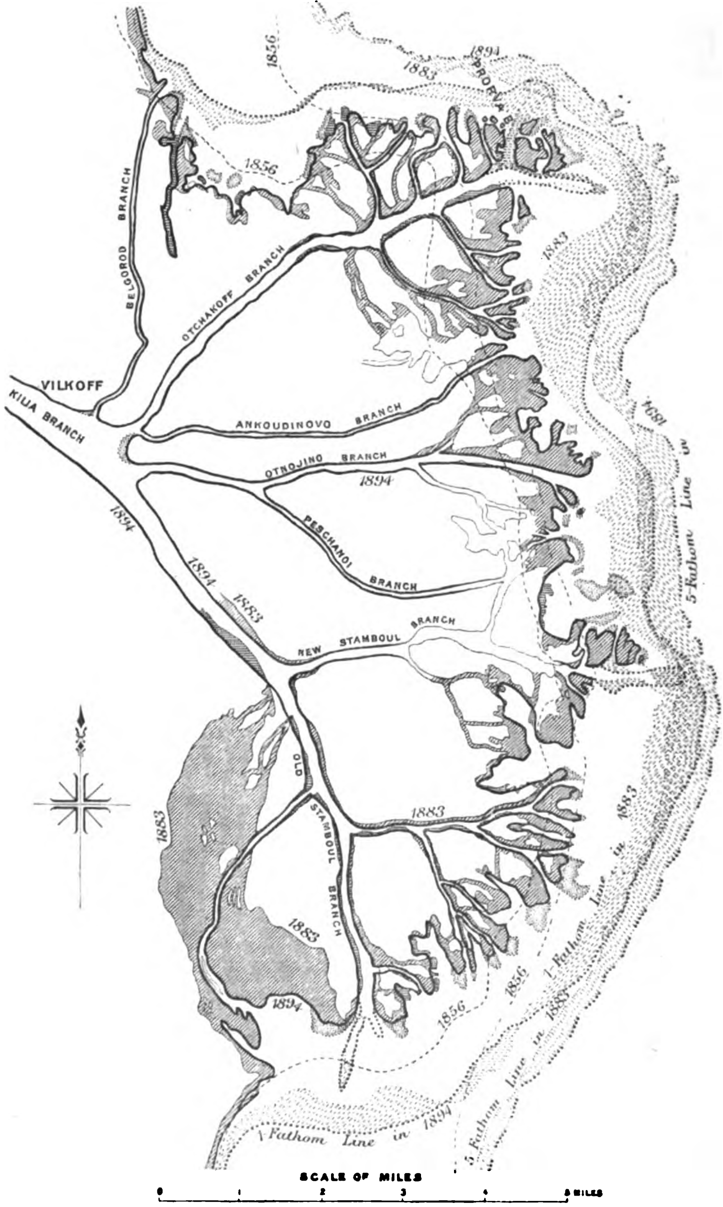
Kilia Mouths.—The Otchakoff branch was directed north in 1830, north-east in 1856, east-north-east in 1871, east in 1883, and east-quarter-south in 1894. The average yearly advance of the 1- and 5-fathom lines of soundings, in front of this mouth, to the north-east, between 1830 and 1856, was only 192 and 115 feet respectively; whereas the yearly advance towards the east, between 1856 and 1883, was 489 and 437 feet, and between 1883 and 1894 was 236 and 291 feet respectively. The total advance of the 1- and 5-fathom lines eastwards amounted to 5,600 and 4,800 feet respectively from 1856 to 1871; 7,600 and 7,000 feet from 1871 to 1883; and only 2,600 and 3,200 feet respectively from 1883 to 1894, *Fig. 1.*

The yearly average advance of the 1- and 5-fathom lines in front of the coast, between the Otnojino and New Stamboul mouths, was 177 and 185 feet respectively between 1830 and 1856; 213 and 133 feet between 1856 and 1871; 317 and 375 feet between 1871 and 1883; and 318 and 273 feet respectively between 1883 and 1894. The total advance of these fathom lines amounted to 11,600 and 11,300 feet from 1830 to 1883; 7,000 and 6,500 feet from 1856 to 1883; and 3,500 and 3,000 feet from 1883 to 1894.

At the mouth of the Old Stamboul branch, the average yearly advance of the 1- and 5-fathom lines towards south-south-east was 230 and 134 feet between 1830 and 1856; 200 and 7 feet between 1856 and 1871; and 125 and 167 feet respectively between 1871 and 1883; whilst there was an average yearly retrogression of the 1-fathom line of 45 feet, and a yearly advance of the 5-fathom line of 109 feet between 1883 and 1894. The advance of these lines of soundings towards south-south-east was 10,500 and 5,600 feet from 1830 to 1883; 4,500 and 2,100 feet from 1856 to 1883; and 4,000 and 3,300 feet respectively from 1856 to 1894, or 105 and 87 feet per annum. The advance of the 1-fathom line towards the south was 6,600 feet from 1830 to 1856; 2,000 feet from 1856 to 1871; 1,000 feet from 1871 to 1883; and 2,000 feet from 1883 to 1894, or an average of 132 feet annually between 1856 and 1894.

These figures show that, at the Otchakoff mouth, the average yearly advance of the 1- and 5-fathom lines towards the east, between 1856 and 1883, was three times as great as the advance towards the north-east between 1830 and 1856; whereas, on the

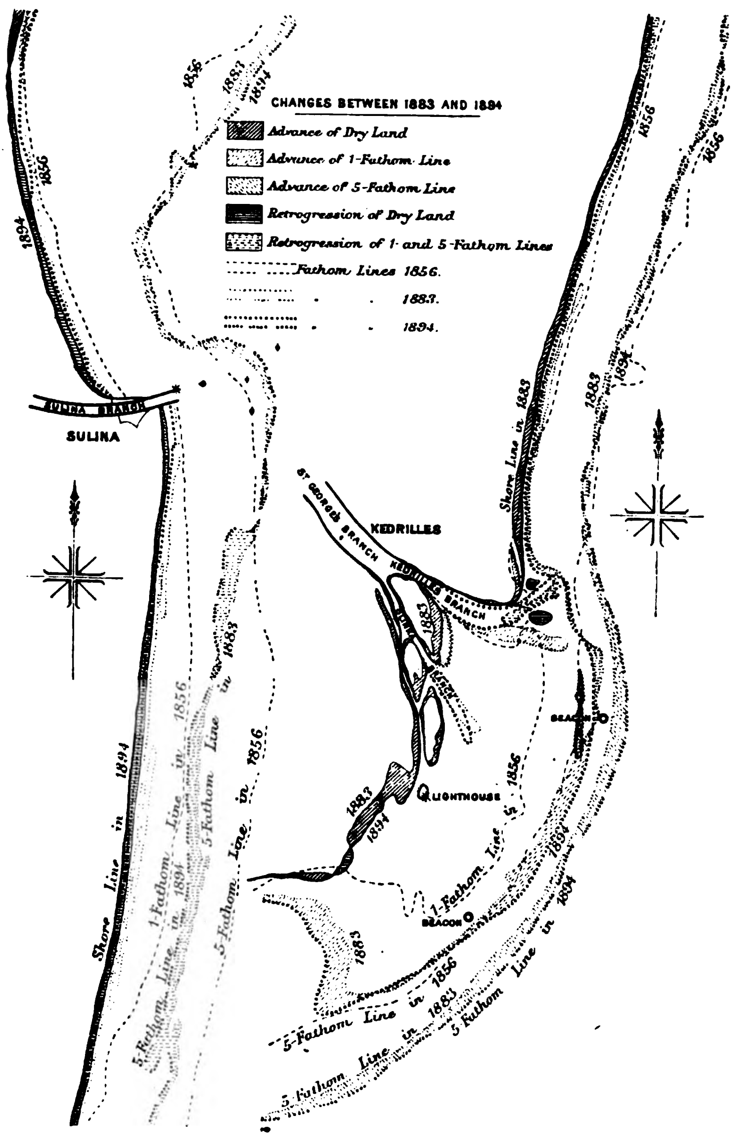
Fig. 1.



Scale $\frac{1}{150,000}$.

KILIA MOUTHS.

Fig. 2. *Fig. 3.*



Scale $\frac{1}{150,000}$.

SULINA MOUTH.

Scale $\frac{1}{150,000}$.

ST. GEORGE'S MOUTH.

contrary, the yearly advance between 1883 and 1894 was only about half the average advance between 1856 and 1883. This reduction during the last eleven years is accounted for by the smaller number of great floods, as well as by the formation of the new Prorva branch which carries a portion of the discharge, and of the sediment of the Otchakoff branch, straight to the north. The unusually rapid advance of the Otchakoff mouth, about 2 sea-miles eastwards, between 1856 and 1883, was attributed by Sir Charles Hartley, in his Report of November 1883, to the ever-increasing discharge of the Otchakoff branch, and the remarkable succession of great floods during twelve years, which causes also produced the increased rate of advance of the coast between the Otchakoff and New Stamboul mouths between 1871 and 1883.

The diminution in the rate of progress of the accretions of the Kilia delta towards the south-south-east, notwithstanding the exceptional floods between 1871 and 1883, indicates that not only has the diversion of a considerable volume of the discharge of the Old Stamboul branch to the northern branches promoted the accumulation of deposit in front of the other Kilia outlets, and diminished the rate of advance of the 1-fathom line at the Old Stamboul mouth, but also that this fortunate reduction in the rate of advance of the shore towards south-south-east is partly due to the erosion by the waves, the action of which is more marked in proportion as the south-east angle of the projecting Kilia delta advances seawards. On the other hand, the southward advance of the Old Stamboul mouth has averaged 182 feet a year between 1883 and 1894, as compared with 111 feet annually between 1856 and 1883, and 181 feet between 1830 and 1883.

Sulina Mouth.—About 4 miles to the north of the Sulina jetties, the 5-fathom line advanced about 1,200 feet from 1883 to 1894, as compared with 1,800 feet from 1871 to 1883; then, somewhat nearer the jetties, this line approximates to the 5-fathom lines of 1856, 1871, and 1883; whilst at 2 miles north of the jetties, the 5-fathom line advanced 1,500 feet from 1883 to 1894, instead of remaining stationary as it did between 1871 and 1883, *Fig. 2.* A powerful scour by the sea has occurred along the coast, and in depths of 1 fathom, for 2 miles to the north of the jetties, where the retrogression has been 500 feet from 1883 to 1894, and 1,100 feet from 1856 to 1894. The average yearly advance of the 5-fathom line between 1883 and 1894, has been 32 feet at about 1 mile to the north of the jetties, 45 feet in front of the mouth, and 32 feet ½ mile to the south; whereas the advances, in the same places, between 1871 and 1883, were 42 feet, 113 feet, and

42 feet a year. About 1 mile south of the jetties, the 5-fathom line receded 1,500 feet from 1883 to 1894, in place of an advance of 600 feet from 1871 to 1883.

The Coast between the Sulina and St. George's Mouths.—From 2 to 8 miles to the south of the Sulina jetties, the retrogression of the 5-fathom line averaged 750 feet from 1883 to 1894, in place of 600 feet from 1871 to 1883, *Fig. 2.* From the eighth to the ninth mile, the 5-fathom line has been stationary since 1883; whilst it receded 200 feet from 1871 to 1883; and from the ninth to the fourteenth mile, the advance of this line has been 200 feet from 1883 to 1894, as compared with an advance of 90 feet from 1871 to 1883.

As regards the relative positions of the 1-fathom line in 1856, 1871, 1883, and 1894, between the Sulina and St. George's mouths, with the exception of a slight advance near the root of the southern Sulina jetty, there has been a continuous retrogression of about 43 feet annually along the fourteen miles between these mouths. The erosion of the coast has been nearly in the same proportion.

St. George's Mouths.—Along the six miles in front of the Kedrilles and Olinka mouths, the advance of the 5-fathom line averaged 450 feet from 1883 to 1894, *Fig. 3,* 1,300 feet from 1871 to 1883, and 967 feet from 1856 to 1871.

Summary of Changes since 1883.—(1) The erosion of the coast north and south of the Sulina jetties has unceasingly continued, *Fig. 2.* (2) The annual rate of advance of the deposits of the Kilia mouths seawards has not for the most part been so great as in previous years, and much less at the Sulina and St. George's mouths, as indicated for the 5-fathom line in the following Table:—

Position of 5-fathom Line.	Direction.	1856–71. Annual Advance.	1871–83. Annual Advance.	1883–94. Annual Advance.	1856–94. Annual Advance.	1830–94. Annual Advance.
		Feet.	Feet.	Feet.	Feet.	Feet.
Opposite Otchakoff mouth	E.	320	583	291	395	266
Between the New Stamboul and Otnojino mouths .	E.	133	375	273	250	223
Opposite Old Stamboul mouth . .	S.S.E.	7	167	109	87	106
In front of Sulina mouth	E.	40	113	45	59	
In front of St. George's mouths .	E.	64	108	41	68	

The slow advance of the deposits in front of the St. George's and Sulina mouths, in comparison to their rapid increase in front of the northern Kilia mouths, *Figs. 1*, *2*, and *3*, may be attributed, irrespectively of the relative volumes of water discharged by these branches, to three principal causes, namely, (1) the stronger action of the littoral current; (2) the more erosive effect of the waves on the sea-bottom during the prevalence of strong winds from the north to north-east; and (3) the much flatter slope of the bed of the sea in front of the Kilia mouths, especially the Otchakoff mouth, than in front of the Sulina and St. George's mouths, as the sea becomes shallower towards the north.

The very marked reduction in the annual rate of advance of the 5-fathom line between 1883 and 1894, all along the coast of the delta, as compared with the advance between 1871 and 1883, may be principally attributed to the notable diminution in the yearly volume of water discharged between 1883 and 1894, in comparison to the volume annually discharged in the twelve preceding years. This accords with the theory propounded by Sir Charles Hartley, in his first Report to the Commission, in October 1857, that the distance of the bar from the coast in front of a mouth is, to a great extent, proportionate to the volume of water discharged by that mouth. It must, however, also be borne in mind, as he remarks in his last Report, that, in comparing the changes during different periods, the favourable or unfavourable action of the winds, and of the littoral currents, may greatly modify the effects produced by the discharge of the river-water, highly charged with alluvium in flood time.

With reference to the interesting question of the eventual absorption of the Sulina mouth by the deposits of the Kilia mouths, though the advance of these northern mouths since 1830 has been very remarkable, sheltering the roadstead of Sulina more and more from northerly winds, nevertheless the advance of the 5-fathom line of the Kilia delta towards the south-south-east has notably diminished in the last eleven years. On the hypothesis, however, that the advance of the 1-fathom line of 181 feet per annum between 1830 and 1894 will be maintained, the incorporation of the Sulina mouth in the zone of deposits of the Kilia delta will only occur 175 years hence.

(*Students' Paper No. 360.*)

"Caissons and Gates for closing Lock- and Dock-Entrances." [1]

By WILLIAM GARNEYS WALES, Stud. Inst. C.E.

IN the course of the discussion, in 1881, on Papers on "Portsmouth Dockyard Extension," it was suggested that an exhaustive comparison of caissons and gates for lock- and dock-entrances would be of value.[2] In subsequent Papers on caissons and lock-gates, no definite conclusions have been arrived at as to their respective advantages; and, in the discussion on "Graving Docks," in 1892, some uncertainty seemed to exist as to the comparative cost of caissons and gates.[3] The Author will, therefore, endeavour to indicate when caissons should be used in preference to gates, and the saving or the increased cost which would be incurred in adopting them. To compare the various structures, some points in their construction and working will first be considered; secondly, the cost, not only of the gates and caissons themselves, but also of the masonry, and concrete, &c., for forming a lock or entrance will be given; and, thirdly, conclusions will be drawn as to when and where they should be used.

Gates.—Lock-gates are made of timber, iron, or steel, or sometimes with iron ribs and timber skin. Of late years steel has been adopted more extensively, and will, in future, probably supplant iron for the construction of gates and caissons. Ordinary timber should not be used in waters in which the *teredo navalis* abounds; and iron should not be used in salt water mixed with sewage, nor in water contaminated with chemicals which act deleteriously upon it. If the water is fairly pure, the adoption of timber or steel for gates will generally be a matter of opinion, except when difficulty is found in obtaining timber of scantlings suitable for large gates, which is partly overcome by constructing the gate in two or three panels. Such gates are necessarily

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[1] This Paper was read and discussed at a Students' Meeting on the 22nd February, 1895, and has been awarded a Miller Prize, Session 1894–95.

[2] Minutes of Proceedings Inst. C.E., vol. lxiv. p. 226.

[3] *Ibid*, vol. cxi. p. 86.

heavy, and must be well braced and strapped to take a blow on the concave side, of which there is always risk when a vessel is being locked; but timber gates are less liable to damage from a blow on the convex side than iron or steel gates. Timber gates have been made for closing entrances of widths up to 100 feet, but since the abandonment of large paddle-steamers such great widths are never required.

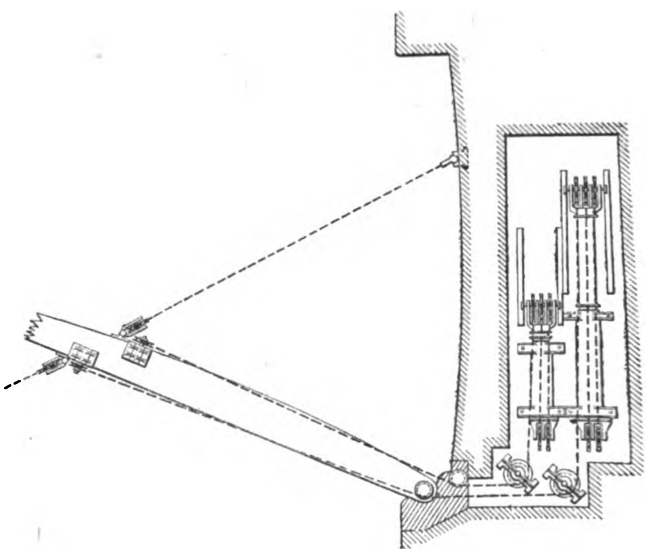
On the Manchester Ship Canal all the gates have been made of greenheart, varying in width between 30 feet and 80 feet. There is no economy in large timber gates, some of those at Manchester being nearly 80 per cent. heavier than a pair of steel gates would have been. They are, however, less troublesome to maintain, and if made of greenheart will last longer, and are preferable for moderate spans. On the other hand, iron and steel gates can be made watertight, and therefore buoyant, so that the anchor-straps and rollers can be relieved of considerable stress. The buoyancy of a gate should be enough to float it at the highest water-level, although in practice a preponderance of weight is always given to the gate.

Rollers are generally provided for gates, except on canals in Holland, where the depth of water is not great and the water-level is nearly constant; but some engineers design gates without them. Such gates require much less power to open them, and are not liable to injury, provided they are buoyant, and have not to be opened or closed when there is a small depth of water over the sill, and, consequently, the greater part of the weight of the gates is hanging. The Author considers that they are a necessary evil, especially in entrances to commercial wet docks, where gates are opened and closed much more frequently than at graving-docks; but he considers they would work better if the spear-rods were attached to springs or balance-levers, so as to yield to any obstacle or irregularity on the roller-path. Sometimes rollers have been found to have afforded no support for a considerable time, without any injury to the gates, proving that gates are generally designed to bear their own weight without being supported by rollers; but the chief objection is the wearing away of the heel-pivot and socket, and the rubbing of the heel-post against the hollow quoins which in time causes leakage and cannot be repaired. Theoretically, the circular form of iron gates is the best, but this involves either a circular sill, or a projecting sill-piece fitted to the gate. For this reason gates, even for large spans, are often made with straight inner faces and cambered outer faces.

Though an ideal method has not yet been arrived at for opening

and closing lock-gates, an advance has been made of late years by placing as little as possible of the gear under water, and providing a clear passage when the gates are open. By far the greater number of lock-gates are opened and closed by chains attached to each side of the gate, at about one-third of the height, and passing round rollers placed in culverts in the lock walls, up to the hauling hand or hydraulic winches, or to hydraulic rams with multiplying speed-gear. The more modern "overgate" system of opening gates may be seen at Burntisland, Liverpool, the Manchester Ship Canal, and Bombay. In this system, the ends of the hauling-chains

Fig. 1.



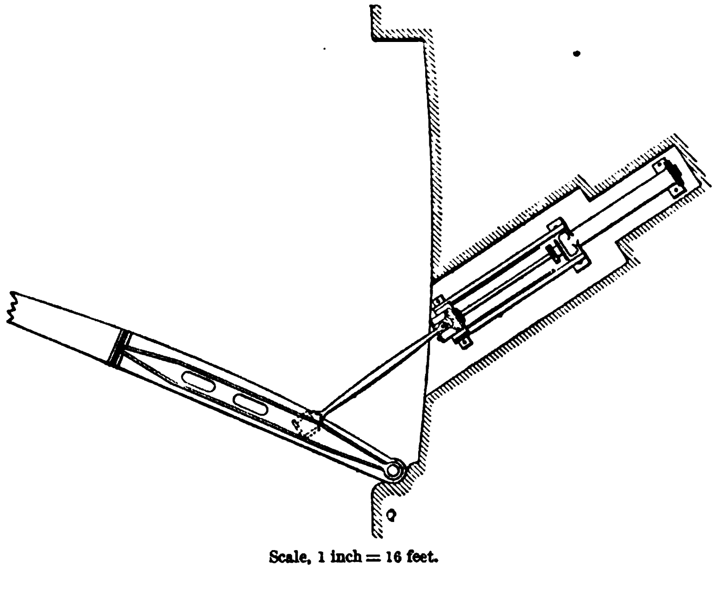
Scale 1 inch = 16 feet.

are fixed to the lock-walls instead of to the gates, and pass over swivelled sheaves on the back and front of the gate, *Fig. 1*, at a point corresponding with that at which the end of the chain is usually fixed, and thence over sheaves on the top of the gate and at the back of the heelpost, to the hauling-machinery. This is usually a hydraulic ram placed in a box below the quay, provided with multiplying sheaves to increase the travel of the ram. The advantages of this system are that each leaf can be opened and shut from the same side, so that if small crabs are employed, two engines with double crabs will be sufficient, instead of four engines with single crabs as in the old method; and the rollers and

chain-ways are dispensed with. These latter, being ordinarily under water, are difficult of access for the repairs which are often required. Chains for opening gates, however, have the disadvantage of reducing the effective cross section of the entrance, and are always liable to foul passing vessels, necessitating a large amount of slack chain.

On account of these objections, the direct-acting ram has been adopted at Barry, Leith, and the West India Docks, London. The machine at the Barry Docks has already been described,[1] but that at the West India Docks differs somewhat from it. The

Fig. 2.



Scale, 1 inch = 16 feet.

cylinder, instead of oscillating on trunnions as at Barry, is fixed, *Fig. 2*, and the power is communicated from the piston-rod to the top of the gate by a connecting-rod which, by means of a cross-head, and vertical and horizontal pivot-pins, is free to turn in any direction.[2] The cylinder and ram in this class of machine have of necessity to be placed near the heel-post of the gate, in order to shorten the stroke of the ram and to reduce the amount of oscillation of the cylinder if made to oscillate. In order that the power

[1] Minutes of Proceedings Inst. C.E., vol. ci. p. 149.
[2] *Engineering*, vol. lviii. p. 539.

may be applied to the gate farther from the heel-post than the ram or connecting-rod, there is a girder or radius arm, one end of which is fixed to the heel-post, and the other end to a bracket attached to the gate at two-thirds of its length from the heel-post, so that the power is applied to the gate at that point. Although by this method of opening and shutting gates chains are dispensed with, and no machines or gear under water are required, yet the application of power to the top of a gate is wrong, the proper point being at the centre of pressure of the gate, one-third of the height of the water above the bottom of the gate. The use of direct-acting rams should form an inducement to discard gate rollers, for should anything become jammed between the roller and the roller-path, or should the gate work stiff, it would be subjected to undue strain. Moreover, in the event of a mishap occurring to the cylinder or ram, the gates cannot be worked by hand, as an ordinary gate-crab can be if the engine fails. In such a case, a gate has to be moved by ropes and a capstan, which may be very inconvenient.

Caissons.—Caissons are of two types, viz., ship- or floating caissons, and sliding or rolling caissons. The first type comprises those which are raised and floated out of their position; the second, those which, while resting on the bottom, are hauled into chambers in the side of the lock, either by sliding over ways which have a smooth polished surface, or on rollers fixed to the masonry or to the bottom of the caisson.

There are three or four distinct classes of ship-caissons, which are distinguished by having one, two, or three water-tight decks, or none at all, and by the number and position of the air-chambers and water-tanks. The most primitive form of caisson is merely a hull without any internal compartments, but carrying sufficient ballast in the bottom to adjust flotation and to give stability. It is sunk by admitting water to the interior, which is afterwards pumped out to raise the caisson. Such caissons are not often designed now, as the pumping is expensive and slow, except for graving-docks where the water ballast can be run into the dry dock without pumping.

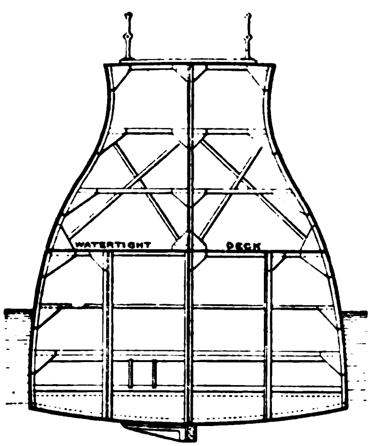
A common form of caisson is that divided into three compartments by two water-tight decks. Under the first, or lower, deck the ballast is placed, and between the first and second water-tight decks an air-chamber is formed, of sufficient capacity to float the caisson; sometimes also a water-tank is provided in this space. Above the second deck, the water is allowed to flow through valves or flood-holes into and out of the caisson as the tide rises and

falls, so that there is no tendency for a rising tide to float it; and at the top of the caisson, under the roadway deck, is another tank, which when filled, keeps the caisson aground, but when emptied allows the caisson to rise and float clear of the groove. To sink it, water is admitted to the lower tank, or the top tank is filled by means of a hose. A caisson of this type is suitable for a graving-dock, but not for an entrance to a wet dock in an exposed position, for the following reason: No matter how high the water-level is, the caisson, when the top water-tank is emptied, will continue to rise until its flotation-line attains the level of the tide, and will thus, at high tide, expose a large freeboard which, with a gale blowing, would make it unmanageable. More complete control can be obtained by dividing the tidal chamber into compartments by water-tight bulkheads. The flow of water in the tidal chambers can then be regulated by valves, and by excluding a portion of the tide, the caisson is given additional buoyancy. By allowing the water in the top tank to escape, the caisson will rise, and will then lose some of the buoyancy given by the tidal chamber, attaining a new flotation level. In this manner, the rise of the caisson can be regulated, which should never be more than 3 feet, in order to clear the groove and float away. This form of caisson is suitable for dock-entrances where the range of tide is not great, but different conditions of tide require different types of caissons, as shown by a caisson designed for the Bute Docks, Cardiff, *Fig. 3*, and one for Kowloon, Hong Kong, *Fig. 4*. In the former the caisson was for a dry dock, and had to float and be stable in only 9 feet 7 inches of water, and also in 26 feet of water. The displacement or buoyancy at the lowest water-level had therefore to be equal to the weight of the caisson and its fittings, together with 120 tons of iron ballast in the bottom of the caisson, needed to bring the centre of gravity below the centre of buoyancy. The other caisson, *Fig. 4*, was not required to work in water varying in level to any great extent, and is therefore more ship-shape.

In designing a caisson, its centre of gravity (including ballast) should be carefully worked out, and also the centre of buoyancy. A caisson should, at flotation-level, have its centre of gravity about 18 inches below the centre of displacement of the immersed part, to ensure sufficient stability for safe working; but if the caisson has no air-chamber and tidal deck, it may have the centre of gravity above the centre of buoyancy, provided it is not above the metacentre. For safe work, the centre of gravity should be about 2½ feet below the metacentre.

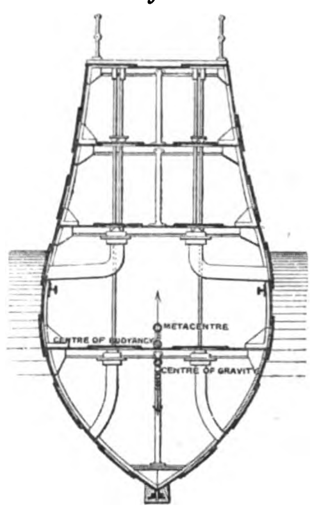
Great strength is required in the stems and keels of a caisson, to withstand the pressure of the water over the area of one side of it. The requisite strength and stiffness is given to the structure by stringers, horizontal decks, struts, and bracings; and additional struts and stays or columns will be required if the caisson is to form a roadway for railway traffic. When a caisson is designed for a dry dock, it is not always provided with pumps; in which case, when sunk, it can only be raised by pumping out the dry dock in order to discharge the water from the lower portion of the caisson. To guide a ship-caisson into the groove when sinking it, two chocks should be kept ready to slip into the groove

Fig. 3.



SHIP CAISSON. BUTE DOCKS. CARDIFF.

Fig. 4.



SHIP CAISSON. KOWLOON. HONG-KONG.

Scale, 1 inch = 16 feet.

on each side, which will give the caisson an even overlap on the masonry. To prevent a caisson from rising, should the water-tank by any chance become empty by leakage or otherwise, locking-flaps on each side of the entrance should be provided, held down by straps competent to resist an upward pressure equal to the weight of water-ballast in the top tank. With a sliding caisson, strong iron girders would take the place of the flaps. Some of the modern caissons in the Government dockyards have been fitted with four small capstans on the roadway deck, so that complete control may be exercised over them.

Sliding caissons are not so varied in design as are ship-caissons;

they are usually box or rectangular in form, and therefore the calculations for stability do not present many difficulties. Opinion differs as to whether rolling or sliding caissons are the better kind. Many rolling caissons have certainly worked for years without interruption; but it is after these few years that they are most likely to fail. To inspect or repair sliding caissons, the caisson recess is generally built with a stop-groove across the entrance, enabling a temporary dam to be put in. The roadway deck has to be about 2 feet below the coping-level, so that the caisson may pass under the recess decking. When the traffic is light, it is not always necessary that the roadway should be level throughout. If therefore the ends of the deck are hinged, they can be ramped up to the coping; and with the ends lowered, the caisson can be drawn into the recess. When it is imperative that the deck of the caisson should be level with the coping, one of the four following methods may be adopted:—In the first method, the deck is fixed at the lower level, and when the caisson has been drawn out of its recess and placed in position, and the water-ballast has been removed, the caisson will rise until it bears against girders or stops firmly secured to the masonry, when the deck is level with the coping. Sufficient water-ballast must be removed so that the buoyancy may exceed the live load which may be expected to come upon the caisson. Instead of floating the caisson, the deck is sometimes raised to the coping-level within the body of the caisson; but the more general method is an automatic balanced falling-deck, or folding-bridge, on Kinipple's principle.[1] The fourth method is to hinge a portion of the recess-cover nearest the dock, and, by lifting up the flap, the caisson may be started and drawn into the recess over inclined sliding ways. The objection to this is that more power is required to draw the caisson than would be necessary in any other method.

The weight of a caisson on the sliding ways is not great, on account of its being partially buoyant, only just enough weight to steady it when moved being necessary, and the hauling-power required is therefore small. This power is usually obtained by a small hydraulic engine, placed at the back of the caisson-chamber; and is communicated to the caisson by two endless chains, one on each side, running over fixed wheels at the outer end of the chamber and gearing with wheels on a swivelling crosshead attached to the caisson. Only one engine is required

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[1] Minutes of Proceedings Inst. C.E., vol. lxv. p. 317 and Plate 8, and vol. cxi. p. 53.

for working a sliding caisson, instead of two, or sometimes four, needed for gates. With a ship-caisson, no hauling-gear or machine is necessary, beyond the capstans which are used at a lock- or dock-entrance, although small capstans on the deck of a ship-caisson are always advantageous.

Cost.—In comparing the cost of gates and caissons, that of the masonry and concrete, &c., in the lock-walls and the foundations must be taken into account, because the length of entrance will vary in each case. As regards the cost of the caissons and gates, the Author has arrived at an average price per square foot of nominal area of opening, from a number of structures designed for ordinary circumstances. The nominal area of opening is the width of the entrance at coping-level multiplied by the height over the sill to coping-level, the batter of the sides and the radius of the invert being neglected. By taking the price per square foot of entrance instead of per square foot of gate, the relative cost of each is seen at once. It is difficult to arrive at the cost of caissons and gates, as it varies according to the circumstances which govern their design. For example, the ship-caisson at the Bute Docks, *Fig. 3*, cost nearly twice as much as another caisson would for ordinary conditions. The difference in cost per square foot of caissons, due to different widths of entrances, is almost inappreciable; and, therefore, the following prices may be taken at the present time for caissons of any size, including the cost of all machinery connected with the caissons and gates. Six sliding caissons cost, on an average, £4 6*s.* per square foot of entrance; seven ship-caissons cost £2 2*s.*; and eight pairs of gates cost £2 1*s.* There is, therefore, not so much difference between the cost of ship-caissons and gates as might be expected on comparing their cross-sections—a result which is attributable to the greater length of the gates, and also to the gate-machines. The price of iron gates has been given as £1 15*s.* per square foot of gate,[1] which would be about £1 19*s.* per square foot of entrance, and a little more if the cost of gate-machines is included. Caissons, however, afford a roadway-bridge of a width of between 10 feet and 18 feet, and, therefore, the cost of a bridge must be added to that of the gates to present equal advantages. The cost of a bridge again varies whether it is a rolling- or a swing-bridge; but the Author considers that £2,100 may be taken as an average price for a bridge (including foundations) spanning a 60-foot lock. To obtain the cost of masonry, concrete, &c., in the

[1] Minutes of Proceedings Inst. C.E., vol. lv. p. 72.

walls and foundations of an entrance or lock, the Author designed an entrance for a pair of gates, one for a ship-caisson, and another for a sliding caisson. In both cases the width of entrance at the coping level was 60 feet, with a height of 34 feet over the sill to the coping. The designs were similar, except that for the gates the walls of the entrance were made plumb and the inverts elliptical, as most nearly resembling in section the type of merchant vessel now being built. Unless a ship-caisson has only to stop one way, in which case one face of the groove on one side of the lock may be cut away, the lock-walls cannot well be made plumb; as the caisson is made to swing out of its groove, not only by pushing it well home into the groove on one side, but also by the clearance given to the caisson when rising by the batter of the walls. The batter given to the walls in this case was 1 in 24; and the caisson groove was made deep, as it always should be. The construction adopted was similar to the latest practice on the Thames, as exemplified by the new entrance of the West India Dock.

The results tabulated below show an economy in ship-caissons in every instance considered:—

——		Ship-Caisson.	Gates.	Sliding Caisson.
		£.	£.	£.
Sixty-foot dock-entrance with single roadway across . .	Cost . .	8,900	13,600	16,700
Sixty-foot dock-entrance without roadway across . . .	,, . .	8,900	11,290	16,700
Sixty-foot dock-entrance with reverse caissons and gates and with single roadway .	,, . . .	8,900	22,000	16,700
Sixty-foot lock with single roadway across	,, . . .	17,800	27,200	33,400

Comparative Advantages and Disadvantages of Caissons and Gates.—When land is valuable, a saving can be effected by reducing the length of a graving-dock or a lock by using caissons instead of gates, particularly in the case of a lock, or where reverse gates are necessary. Ship-caissons require less length than sliding caissons. They can be examined, repaired, and painted by being tilted over—or by being docked, put on a slip, or laid on a gridiron, without difficulty; whereas gates require heavy-lifting lighters, or temporary staging and lifting-gear for the purpose of landing

them. Ship-caissons can be painted all over outside if the tide allows, by first painting on one side at low water; and then, by reversing the caisson in the stops, the other side can be dealt with at the next tide. Caissons can be made to fit several entrances, or, by being placed in outer or inner stops, can be used for adjusting the lengths of locks and graving-docks to suit that of a ship, thus saving water in one case and pumping in the other. The stop-grooves for caissons are easier to face, and therefore a more water-tight junction is obtained with a caisson than with hollow quoins and sills, which are difficult to face and possess a greater length of meeting-face. Caissons provide a single roadway across a lock for carrying heavy loads, such as boilers or rolling-stock; and dispense with swing-bridges, which are not only expensive, but obstruct the quay when a vessel is being docked or locked. Both floating and sliding caissons will act either way, and do duty for reverse gates; and therefore a lock provided with two caissons could (if the foundation were good), in the case of a naval war, be converted into a dry dock by pumping the water out of it.

On the other hand, gates are more handy to open and shut, and quicker in operation. A pair of gates for a 60-foot entrance could be opened in one or two minutes; a sliding caisson in between two and four minutes; whilst a ship-caisson would probably require ten to twenty minutes to raise and float it clear of the entrance. Gates and sliding caissons can be opened at any state of the tide, by the help of two men and one man respectively, provided that the water-level is the same on both sides of the gates. This is not the case with ship-caissons, which require several hands, and a certain draught of water, to enable them to be floated while retaining their stability; and further they sometimes become unmanageable in a gale. Gates when open, and sliding caissons when drawn back, offer no obstruction either in the entrance or dock; whilst a ship-caisson, unless a recess is made for it, is liable to get in the way of shipping and be damaged.

Concluding Remarks.—Caissons, especially ship-caissons, are not suitable for commercial docks in tidal rivers, where it is of the greatest importance that entrances should be capable of being opened and closed with rapidity and ease, with perhaps the tide flowing and a gale blowing. The only exception is in the case of a graving-dock, where a ship-caisson answers all purposes, is cheaper, and pumping is seldom required, as the water ballast can be run out into the dock. Thus out of thirty-two of the larger graving-docks on the Thames, twenty-one are closed by caissons. At Government dockyards, where the movement of shipping is

less frequent, both sliding and ship-caissons have been used for dock-entrances from tidal rivers. The former are best suited for such positions, but are sometimes forbidden by local circumstances. Thus at the Chatham Extension Works, 1869, the original intention of having sliding caissons was abandoned on account of the vast accumulation of mud which took place in the docks. Ship-caissons, as a rule, are better suited for non-tidal entrances to docks and Government dockyards, where space can more readily be found for berthing the caisson when not in use.

In conclusion, ship-caissons are adapted for dry docks, and for locks and entrances in sheltered and non-tidal positions; sliding caissons for locks and entrances in tidal and sheltered positions; and dock-gates for entrances in exposed positions, and for commercial wet docks.

The Paper is accompanied by five tracings, from which the *Figs.* in the text have been prepared.

(*Students' Paper No. 357.*)

"The Glasgow District Subway."[1]

By ANGUS MATHESON STEWART, Stud. Inst. C.E.

A WANT long felt in Glasgow has been some means of rapid transit between the centre of the city and the outlying residential districts. In 1887, a Bill was promoted in Parliament for the purpose of obtaining powers to construct a subway or underground passenger railway, connecting Partick and the north-west districts with the centre of the city. Powers were refused; the principal reason for the refusal being the novel system of working which was proposed. The principal aim of the method referred to was the reduction of first cost—a very important matter with a new and independent company. The idea was to construct a tunnel of sufficient width to accommodate a train running on either of two double lines of rail the centres of which were 3 inches apart. Trains going in one direction to use one line and those going in the opposite direction to use the other, passing one another at the stations which would have island platforms. The stations to be equidistant, in order that passing trains would arrive at them almost simultaneously. The motive power to be cable or electricity.

The system mentioned having been abandoned, in the following year, 1888, powers were applied for to construct a subway, consisting of two endless tunnels, connecting the districts to the south, as well as those to the west and north-west, with the centre of the city, and were again refused; the principal reason for this refusal was that, where it was intended to pass under the River Clyde, the proposed level of the tunnels was not at a sufficient depth to admit of future deepening of the river to any great extent. In the year 1889, the Glasgow Harbour Tunnel Company obtained powers to construct tunnels under the harbour at Finnieston. A precedent having been thus established—so far as the

[1] This communication was read at a meeting of the Glasgow Association of Students of the Institution on the 28th of January, 1895, and has been awarded a Miller Prize, Session 1894–95.

river was concerned—powers were again applied for, in the year 1890, to construct a subway, differing somewhat in detail from that proposed in 1888, and were granted.

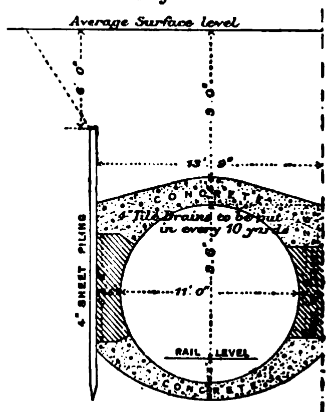
General Description.—The total length of the subway is $6\frac{1}{2}$ miles. There are fifteen stations, the average distance between them being less than $\frac{1}{2}$ mile. Each of the two tunnels which form the subway is 11 feet in diameter, and they are constructed between 3 feet and 6 feet apart. The stations are 28 feet wide and 150 feet long. Each station has an island platform, 10 feet wide, to which access is obtained at one end by means of stairs and short passages, 6 feet to 8 feet in width, with a total rise of 20 feet to 30 feet to the street above. There is to be an endless traction-cable in each tunnel, and both cables are to be driven from one power-station. The gauge of the railway is to be 3 feet 9 inches. It is intended to run trains consisting of two cars, each car to be 41 feet long over all, and to seat forty-two passengers. The cars will be very roomy, and will be capable of carrying about double this number if necessary.

As soon as powers were obtained, the survey for the working plans was commenced. A double series of lines was run round the route to be followed, and from these the details on the surface were surveyed for a distance of 200 feet to 300 feet on each side of the intended centre-line. This survey having been plotted to a scale of $\frac{1}{500}$, the plan of the subway was drawn and the route was sectioned. Where the subway passes through private property the property was bought outright, as it was considered more economical to adopt this course than to pay high rates for way-leave. For the greater part of its length, however, the subway follows the line of streets, under which it has a free right of way. The line being roughly circular in plan, the total amount of curvature is considerable. The sharpest curves are of 10 chains radius—an easy curve on a cable-railway. The ruling gradients are very slight; but advantage has been taken of the practicability of steep gradients in passing under the River Clyde, where a vertical curve with a maximum gradient of 1 in 18 is introduced. Each station is approached from both sides by slight rising gradients. The formation in the southern and low-lying districts through which the subway passes, consists of alluvial deposits—running-sand, clay and mud. In the northern and north-western districts the lie of the land is high and there is a rock formation. In the soft formation, the "cut-and-cover" method of construction was employed wherever practicable, but elsewhere tunnelling by the "shield" system was employed. In

the rock formation the tunnels were formed by the ordinary method of blasting.

Construction by "Cut-and-Cover."—Where the "cut-and-cover" system was adopted, the tunnels were built according to the cross section shown in *Fig. 1*, and the method of construction was as follows :—

Fig. 1.



Two rows of 4-inch sheet-piling, 27 feet 6 inches apart, were driven to the formation-level, the piling being carried to the surface of all streets traversed. A trench was cut between these to the level of the intrados of the double concrete arch. At the level of the arch, and 7 feet apart, spaces 2 feet by 2 feet by 1 foot were cut through the piling. The bottom of the trench having been carefully shaped with the aid of profiles, the double arch was laid, care being taken to pack the spaces cut through the piling. Two coats of asphalte, each $\frac{3}{4}$ inch thick, having been poured over the arch, the trench was filled up and the surface of the ground was restored. The arch was set in lengths of about 15 feet. The excavation underneath the arches was proceeded with in one tunnel at a time. As the first tunnel advanced, one-half of the double invert was laid, and one side-wall and one-half of the centre wall were built—the arch being supported meanwhile on one side by the dumpling of the other tunnel, and on the other side by the grip obtained on the piling by means of the spaces cut through and filled with concrete. As the second tunnel advanced, the other half of the invert was put in, and the other side wall and half of the centre wall were built—the arch, in this case, being supported on the one side by that half of the centre wall already built and on the other side by the grip on the piling. When passing through vacant ground, this method was varied—the trench being carried in the first instance down between the piles, which were ranced across, to the formation-level of the invert. The invert was then put in, the side-walls were built, and the arches were turned on centering in the open. At intervals of 25 yards, manholes, communicating between one tunnel and the other, were constructed. They are 3 feet wide, 5 feet high, and are arched at the top. Every 10 yards, 4-inch

tile drains were built into the centre wall, and water collecting in the hollow between the arches drains through these into the tunnels. In the centre portion of the arches, the concrete consists of four parts of broken stones or bricks to one part of Portland cement with sand as required. In the haunches it is five to one, and in the invert six to one.

For about $\frac{1}{4}$ mile the material was so soft at the level of the invert that on an attempt being made to build it in the usual manner, the concrete sank into and mixed with the mud. To dry the material, by driving back the water, air-pressure was successfully employed. There was a large escape of air at the sides of the arch, but the requisite pressure of 2 lbs. to 3 lbs. on a square inch was maintained without difficulty. The tunnels were constructed by "cut-and-cover" partially under several buildings. These were supported during construction in the following manner:—Heavy spaced piles were driven outside, and close to the walls of the buildings. These supported a timber staging which was passed in below the walls, and on which the latter rested while the operations were proceeded with underneath them. The tunnels having been formed, the walls were underpinned from the arch with brick. The timber was then removed, any of the piles which passed through the arch being cut out.

Tunnelling in Soft Material.—On those portions of the subway where the material passed through was soft and the surface could not be opened, the tunnels were lined with cast-iron, built in segments. The cross section is shown in *Fig. 2.*

Figs. 3 and *3a* show the details of the segments, each of which is about 4 feet by 1 foot 6 inches, the key-piece being 9 inches by 1 foot 6 inches. These were found to be of a convenient size and weight to be handled, and the soft wood made an excellent and easily-fitted joint. Where not quite watertight, the joints were wedged up with oak wedges. The iron lining was built up inside a shield, which consisted of a cylinder of sheet-iron strongly braced in front. It was fitted with a steel cutting-edge, and to the bracing were fitted eight hydraulic rams. These rams pressed on the completed lining, and by their means the shield was forced forward as the tunnel advanced. Any one of the rams could be worked independently of the others, so that the direction of the shield might be altered as required. They were worked by means of two hand-pumps.

The tunnels were constructed under sufficient air-pressure to drive back the water. This varied between 7 lbs. and 30 lbs. on a square inch. A brick-in-cement stopping closed the entrance

to each tunnel where work was being carried on under compressed air; and into this were built an air-lock for the passage of men and material, a 9-inch pipe to admit the compressed air, a 6-inch pipe, with a valve on each end, for the passage of long rails for the temporary way, a small water-supply pipe, a pipe for supplying the high-pressure air to the grouting-machine, a small pipe through which any water that collected in the tunnels was forced out, and a tube containing wires for signalling by electricity from one side to the other.

The lining was built in lengths consisting of between one ring and three rings of segments, as the nature of the material permitted. A top heading tightly boarded up, with the joints well stopped with clay to prevent the air from escaping, was driven forward a distance of two or three lengths in advance of the shield. A

Fig. 2.

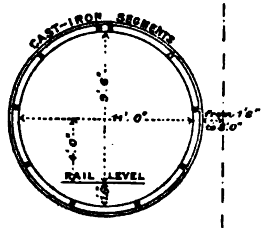
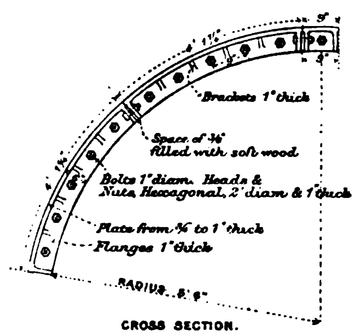


Fig. 3.



CROSS SECTION.

Fig. 3a.

LONGITUDINAL SECTION.

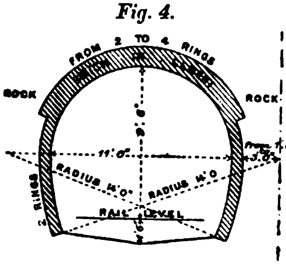
length of this was then opened, from the top downwards. Poling-boards, supported at the one end by the shield and at the other end by the face boarding, and clayed at the joints, were put in as the length was opened out. When a length had been completely excavated and boarded round, holes were bored, and neat Arden lime was grouted in behind the poling-boards under air-pressure of 40 lbs. per square inch. The shield was then moved forward and the iron lining was built up. When the shield had drawn clear, the space between the lining and the poling was grouted with Arden lime through holes left in the centres of the segments.

The most considerable difficulty met with in driving these tunnels was under the River Clyde, in the upper harbour. There, even with the previously mentioned approach gradient of 1 in 18, the greatest amount of cover obtainable in the deepest part of the river, near the north quay wall, was 13 feet. This cover consisted

for the most part of silt. The tunnels were driven southward from the station in St. Enoch Square, and everything went well until the leading tunnel had just passed the quay wall, when the pressure of air inside the tunnel proved to be too great for the strength of the cover and a hole was forced through into the bed of the river. Through this hole the water gained access to, and flooded, the tunnel. It was filled up from above with good stiff clay obtained at another part of the work, air-pressure was again applied, the water was forced out, and tunnelling was recommenced. Operations had only proceeded a few feet when another similar burst took place. This and several others which followed were treated in a similar manner. The bursts at last became so numerous that the contractor gave up the contract. The company took over the plant, and, on the assurance of the engineers that the design, provided due precautions were taken, was practicable, made a special agreement with another contractor to complete the work. As soon as possible a fresh start was made, and the new contractor by carefully regulating the air-pressure according to the state of the tide, and placing thin sheet-iron under the poling-boards in the top of the working for the purpose of distributing the pressure over them as evenly as possible, drove the leading tunnel without another burst to the other side of the river. The second tunnel was also successfully driven, only one burst occurring in it. Careful soundings of the river were regularly taken during the progress of the works, and any deepening of the bed, caused by the scour of the river, was filled up with clay.

Tunnelling in Rock.—The section of the tunnels in rock is shown in *Fig. 4.* The arch is lined with from two to four rings and the side walls with two rings of brick-in-cement. A concrete lining of equal thickness was substituted for the brick where the tunnels were driven through rock of sufficiently good quality to be broken for concrete. The concrete was gauged, five parts of broken stones to one part of cement, with sand as required.

Fig. 4.

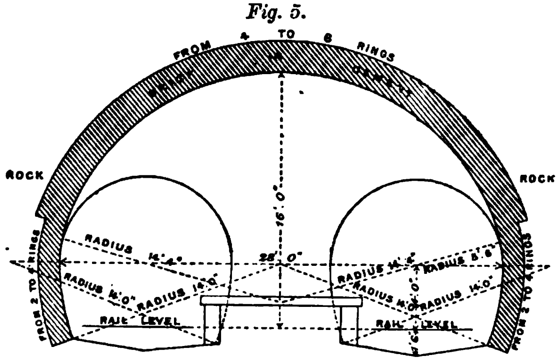


Numerous difficulties, chiefly caused by water, were encountered in the construction of the tunnels. In one place a large quantity of water lying in an old quarry was tapped, and a section of the tunnels about $\frac{1}{4}$ mile in length was completely flooded. In another place, the strata dipped in such a manner that the upper half of the

tunnels penetrated the subsoil. A thick layer of sludge which had at one time formed the bed of a stream lay over the rock. When the face of the leading tunnel entered the bed of sludge, the weight of the traffic in the street above pressed the sludge out into the tunnel, and considerable subsidence resulted. On this being observed, the faces of the tunnels were bricked up, and others to meet these were driven forward under air-pressure and lined with iron segments.

A seam of old coal-waste, which underlies the Hillhead and Partick districts, was met with, and substantial structures of brick-work had to be built on both sides of the tunnels to relieve the arches from thrust. This seam of coal crops out on the banks of the Kelvin to the north of Hillhead, and when the river was high it flooded the

Fig. 5.



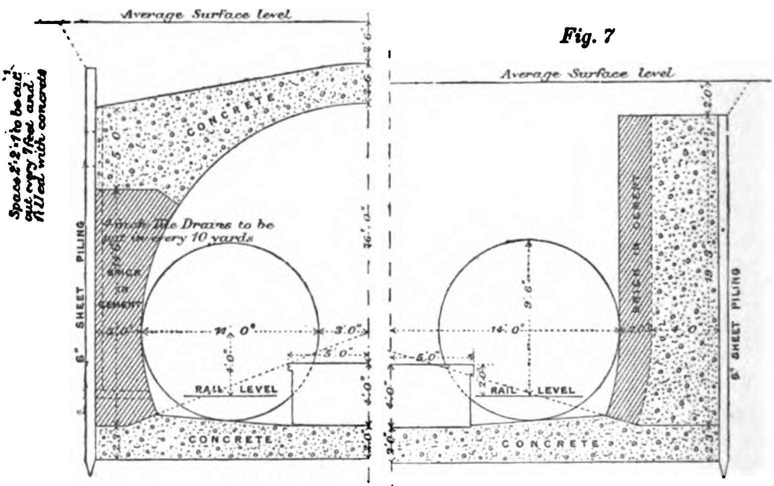
waste and greatly impeded the progress of the work. The greater portion of the tunnels was through rock under streets carrying a large amount of traffic, and they had to be worked from shafts sunk in side streets. These shafts were sunk about ¼ mile apart.

Stations.—The stations are constructed either in tunnel, in covered way, or in the open between retaining-walls. The section of stations in tunnel is shown in *Fig. 5.* They are lined with brick-in-cement, the thickness in the arch being between four and seven rings, and in the side-walls between two and four rings of brick, according to the nature of the material in which they are constructed. The section of stations in covered way is shown in *Fig. 6.* They have concrete arches 2 feet 6 inches thick at the crown and concrete inverts 2 feet thick at the centre. The side-walls are 3 feet thick at the springing of the arch, and are built of brick-in-cement. The section of stations between retaining-walls is shown in *Fig. 7.* The walls are 6 feet thick, faced with an average thickness of 2 feet of brick-in-cement bonded into a backing of concrete.

Drainage.—Wherever a natural fall to the River Clyde can be obtained, drains are being constructed to carry off the water that gains access to the tunnels. Where a natural fall cannot be obtained, the tunnels will be kept dry by pumping.

Power-Station.—The trains are to be drawn by two steel cables, 1½ inch in diameter, one in each tunnel. Both cables are to be driven from one power-station. The power required is estimated at from 1,000 horse-power to 1,400 horse-power. Two main driving-engines are being provided, each of which will be capable of doing all the work; but they are to be so arranged that during times of extra pressure both may be brought into operation. The

Fig. 6. *Fig. 7*



engines are of the single-cylinder non-condensing type. The cylinders are 42 inches in diameter, with a 6-foot stroke. It is intended to drive the cables at 15 miles per hour; but the engines are being so constructed that this may be increased to 16½ miles per hour.

The engineers of the work are Messrs. Simpson and Wilson, of Glasgow, to whose assistants resident on the work the Author is indebted for much of the information contained in this account. The arrangement of the power-plant has been entrusted to Mr. D. H. Morton, Assoc. M. Inst. C.E., Glasgow.

The Paper is accompanied by seven tracings, from which the *Figs.* in the text have been prepared.

OBITUARY.

HAROLD WILLIAM ABERNETHY, third son of Mr. James Abernethy, Past-President, was born in London on the 22nd of October, 1858, and was educated at Westminster School for five years and subsequently from 1877 to 1879 at the Royal Agricultural College, Cirencester, where he obtained a Certificate of Membership and acquired a thorough knowledge of surveying. He then entered his father's office and was engaged for several years chiefly on surveys and in the preparation of designs for marine and hydraulic works. In 1883 he was appointed by his father Assistant Resident Engineer on the important works of the Alexandra Dock at Hull. This dock has a water area of 47 acres, 2 miles of quay-walls from 52 to 62 feet in height, a lock 550 feet long and 85 feet wide, with a depth over its sill of 34 feet at ordinary tides; also two large graving-docks and extensive pumping appliances for supplying the dock with water independently of the turbid river supply.[1] Harold Abernethy was principally employed on the construction of the lock and works at the river front. In conjunction with his fellow-assistant, Mr. G. FitzGibbon, he had charge of the detailed setting out, measuring and supervision of this important section of the undertaking, including much of the difficult foundation work. He likewise assisted in the marine surveying, soundings and current observations which were made in the Humber from time to time. To these works he devoted himself assiduously and saw them through to their completion and to the opening of the dock for traffic in July, 1885. It was at Hull that he gained the practical experience which so well fitted him subsequently to fill the important position of Resident Engineer on a section of the Manchester Ship Canal. At Hull he was a general favourite: he was fond of all athletic sports, a good football and tennis player and a first-rate shot, but never allowed his fondness for outdoor sports to interfere with the due and faithful performance of his engineering duties.

During the year 1887 Harold Abernethy was employed in con-

[1] Minutes of Proceedings Inst. C.E., vol. xcii. p. 144.

nection with the Royal Commission on Irish Public Works, of which his father was a member, on surveys of the River Barrow and for light railways in Ireland. In the same year he went to Egypt to superintend the construction of works for the reclamation of Lake Aboukir,[1] under his father, who was Engineer to the English Company which had obtained a concession from the Egyptian Government.

In 1888 Harold Abernethy was appointed Resident Engineer on the Runcorn section of the Manchester Ship Canal. A length of 7 miles, subsequently extended to 10 miles, was placed under his charge. The works included 3½ miles of river embankment and concrete walls in the tideway, three groups of large locks and sluices of great magnitude, and the difficulty attendant on their execution was enhanced by the necessity of keeping open the traffic of two important systems of navigation during their construction. He continued his duties until the canal was opened for traffic in January, 1894, a period of six years, his practical knowledge, his ready and correct judgment when unforeseen difficulties presented themselves, and his straightforward, manly character being thoroughly appreciated by the Engineer-in-Chief and by all officials and others with whom he came in contact.

His appointment as Resident Engineer on the Manchester Ship Canal works was the last Harold Abernethy was permitted to hold. Intermittent fever had attacked him and all medical treatment failed to alleviate the complaint. In March, 1895, he was recommended a voyage to the Cape; but the fever attacks gradually increased in severity and duration, and he embarked in the Union s.s. "Scot" at Durban on the 22nd of June, on the voyage home. He died on the 9th of July, in his thirty-seventh year, and was buried at sea. He was elected an Associate Member on the 14th of April, 1885, and was transferred to the class of Member on the 14th of November, 1893.

ALFRED COLLETT, son of the Rev. W. L. Collett, M.A., late vicar of St. Stephen's, Hammersmith, was born on the 17th of May, 1854, and received his preliminary education at Dr. Huntingford's school, Wimbledon. After a course of training in the Applied Sciences Department of King's College, London, he was articled in December, 1873, for four years to Messrs. Wilkinson and Smith,

[1] Minutes of Proceedings Inst. C.E., vol. ci. p. 189.

engineers, of Westminster, by whom he was employed in surveying, levelling, taking out quantities, designing gas and railway works, and in the preparation of parliamentary plans and estimates. His first appointment, which he held between May, 1877, and September, 1878, was that of contractor's engineer on the Yarmouth and Stalham Railway. He then acted for nine months as Resident Engineer during the construction of the Lynn and Fakenham line, and afterwards had charge of the erection at Yarmouth of a terminal station, station yard and repairing- and running-sheds, and of extensions of the Yarmouth and Stalham Railway to North Walsham and of the Lynn and Fakenham Railway.

In 1881 Mr. Collett was appointed Engineer, under Mr. Henry Gale, of a mountainous district of the Donna Theresa Christina Railway in Brazil. On its completion he returned to England and was engaged on survey work at Wigan for Sir Douglas Fox. From October, 1883, to February, 1885, he acted for Messrs. Sir John Hawkshaw, Son and Hayter as a District Engineer on the surveys for the Dom Pedro I. Railway in Brazil, being for some months, during the absence of the Chief Engineer, in sole charge of the large staff employed and also representing the Company in Brazil. Mr. Collett was then for three years Resident Engineer and Locomotive Superintendent of the Buenos Ayres and Pacific Railway, having charge of the construction and maintenance of the line. From 1888 to 1890 he was Chief Engineer for the Argentine Government during the construction of the Chilecito, the Chumbicha and Catamarca, and the Salta and Jujuy Railways, acting at the same time as Consulting Engineer in Buenos Ayres to the Pacific Railway Company.

Mr. Collett was next engaged, on his own account, between 1890 and January, 1892, in general engineering work in Buenos Ayres and Monte Video, where he constructed tramways of considerable extent and represented the Low Moor Iron Company and the firm of Messrs. Sharp, Stewart and Company. He also carried out 450 miles of survey for the Interior of Uruguay Railway. In January, 1892, he left South America on being appointed Engineer and Manager of the Barcelona Waterworks. During his residence in Spain Mr. Collett had several opportunities of inspecting the construction of the Monistrol-Montserrat Rack-Railway, a line formed for the purpose of conveying pilgrims and visitors to the monastery situated half-way up the mountain of Montserrat in the province of Catalonia, about 18 miles from Barcelona. As that line possessed many points of interest, he presented to the Institution a brief description of it, which, in conjunction

with two other Papers on Mountain Railways, was read early in the present year.[1]

In February, 1895, Mr. Collett was appointed Resident Engineer and Manager to the Natal and Nova Cruz Railway in North Brazil, where his active supervision was at once successfully employed. His useful career was however destined to be prematurely cut short: during a season of unusually trying heat he contracted yellow fever, which unhappily proved fatal on the 28th of June. Mr. Collett was elected an Associate Member on the 5th of April, 1881, and was transferred to the class of Member on the 5th of April, 1892.

WILLIAM ALFRED ECKERSLEY, born on the 25th of January, 1856, was the son of Mr. William Eckersley, who for upwards of forty years has been a Member of the Institution. After being educated at Marlborough School and at Pembroke College, Oxford, he served a pupilage to his father from 1874 to 1877, during which period he was engaged in the office and on the construction of a short railway, a timber and iron-pile pier and concrete buildings at Thames Haven. He was then for a time assistant to Mr. James Scott on the construction of the Abbotsbury line, now part of the Great Western system, and from 1879 to 1882 had charge of the construction, first, of river-protection works on the Thames, and, subsequently, of a sea-wall and reclamation works at Trouville-sur-Mer, France.

Between 1882 and 1886, he was on the location and construction of the Jerez-Algeciras Railway as an Assistant Engineer, having for the greater part of two years sole charge of the Gibraltar end. He also reported upon the Algeciras-Ronda-Bobadilla line through the Sierra Nevada. Between 1886 and 1888 he was employed by Messrs. James Livesey and Son to survey and report upon the La Libertad and San Salvador Railway in Central America; he partly surveyed and prepared estimates for the Pontevedra-Carril Railway, a line of 20 miles over mountainous country in Galicia, Spain, for Mr. Edward Woods; and for Messrs. Livesey he inspected and reported on seven of the most important lines in Peru, including the Oroya Railway, and made surveys for a light rail-

[1] Minutes of Proceedings Inst. C.E., vol. cxx. p. 25.

way, *viâ* San Roque, to Gibraltar. He then acted in Westminster for Messrs. Livesey as engineer in charge of general work.

From 1889 to 1892 Mr. Eckersley had sole charge for Messrs. Read and Campbell of the survey and construction of the Mexican Southern Railway, a line of 230 miles, on which are seven tunnels, important river-bridges and some heavy mountain work. In addition to that, in 1890 he reported upon and prepared an estimate for the San Luis Potosi Waterworks and made plans for the drainage of Puebla, for a pier at Salina Cruz, and for markets, drainage and waterworks for several towns in Mexico. In 1893 and 1894 Mr. Eckersley was in charge, for Messrs. Livesey, Son and Henderson, of a survey of 260 miles of railway in Mashonaland from the Anglo-Portuguese frontier to Fort Salisbury. During that period he also reported upon and prepared plans and estimates for water-supply and tramways at Fort Salisbury, tramways at Beira and other works in South East Africa. In the autumn of 1894 he proceeded to San Salvador, Central America, to take up an appointment on the Ferro Carril de Santa Ana. He had in connection with this engagement to survey the projected extensions between a station on the Santa Ana Railway, in course of construction, and San Salvador, the capital. His employers, the Central American Public Works Company, of London, took over that line from the Government of the Republic and placed Mr. Eckersley in charge, and through his efficient organization and management the earnings were increased beyond the greatest hopes of the Company. It was during the discharge of these duties that he was struck down by yellow fever and died at Santa Ana on the 23rd of April, 1895, in the fortieth year of his age.

Mr. Eckersley had already displayed great ability as an engineer, while his high character and genial disposition obtained for him universal esteem and respect. He was elected an Associate Member on the 1st of May, 1888, and was transferred to the class of Member on the 16th of October, 1894.

ALFRED GILES, son of Francis Giles, a well-known engineer and a Member of Council of the Institution, was born in London in 1816. He was educated at Charterhouse, and after leaving that school studied with a private tutor, with the intention of going to Cambridge. In early life he desired to become a sculptor

and gave signs of artistic skill of considerable merit which afterwards showed itself in his work wherever elegance of design was possible. His father, however, who, although at first a strenuous and frequent opponent of Stephenson, subsequently became a firm supporter and friend of that engineer, was employed upon so much railway work that he was forced to call upon Alfred to assist in the numerous surveys he had then in hand. Thus at the early age of seventeen, after a short training in his father's office and in the field, Alfred Giles came to be employed in making surveys for the London and Brighton and the London and Southampton Railways. His father was the original engineer of the latter and carried out a considerable part of the line, now the London and South Western Railway main line to Southampton,[1] until the Company got into financial difficulties owing to the impossibility of finding contractors to undertake more than a section of the work at a time. The great railway contracting firms had not yet come into existence, and it often happened that a section in the centre of the line remained uncompleted, owing to the failure of a contractor to carry out the work he had undertaken. After this Mr. Alfred Giles was employed in surveying and levelling for new lines in all parts of the kingdom, and some of the difficulties encountered by him are well described in his Presidential Address to the Institution.[2] In 1846 he laid out the Reading and Reigate Railway, and, his father having died in 1847, and his elder brother, Mr. F. G. Giles, having left the profession owing to ill-health, he continued the work and had executed a large part of the line when it was purchased by the South Eastern Railway Company. In 1857 he was engaged in Italy in surveying the coast-line from Marseilles to Spezia, the inland line from Genoa to Spezia, and another line from Coire to Dipentes and thence over the Lukmanier Pass to Locarno. This scheme involved great engineering difficulties and was ultimately abandoned in favour of the Mont Cenis tunnel. During that time he became acquainted with and enjoyed the confidence of Count Cavour. In 1863 he proceeded to lay out and survey the line from Lemberg to Czernowitz in Galicia, the work being finished under his direction and opened in 1866. Several other railways were surveyed and carried out by him, among them being the Neath and Brecon, the Swansea Vale Junction, and lines abroad. In 1860 he was selected by shareholders in the Great Western Railway Company of Canada

[1] Minutes of Proceedings Inst. C.E., vol. vii. p. 9.
[2] *Ibid*, vol. cxv. p. 1.

to examine that line. He found that there were 4 miles of wooden bridges, involving heavy cost for repairs and at the same time interfering with the traffic, and he recommended the reduction of large spans wherever practicable, so that in case of accident or decay renewal could be easily made.

It was, however, in harbour and dock works that Mr. Giles was more fully engaged. Southampton claimed his greatest care from the year 1838, when assistant to his father, who was engineer to the Dock Company, to which post he succeeded in 1847. Those duties, however, did not entirely take up his time, except when new works were in progress. The several schemes which have made the port so convenient of access at the present time were carried out under his personal direction, with the assistance of his sons, Brydges and George F. L. Giles. From the first Mr. Giles saw the capabilities of Southampton for a great port, and endeavoured to keep pace with the increasing size of ocean-going steamers; but lack of means caused the Dock Company to hesitate to incur the expenditure necessary for the development of the trade which has taken place since the acquisition of the docks by the London and South Western Railway Company.

The early works at Southampton were described by Mr. Giles in a Paper[1] read before the Institution in 1858, for which he was awarded a Telford Medal. The later works chiefly consisted of a graving-dock, which in its day was the largest in the world, and a deep-water quay, designed in 1874 for the express purpose of forming one side of a large tidal dock, which was commenced in 1885 and finished and opened by the Queen in 1890. This dock has an area of 18½ acres, and is 26 feet deep at low-water spring tides. In this work he was ably assisted by his son, George F. L. Giles, as resident engineer. After nearly fifty-four years' service, as Assistant and Chief Engineer, his connection with the Southampton Docks ceased with their transfer by Act of Parliament to the London and South Western Railway Company in 1892.

The difficulty at Southampton was the want of a good foundation, the subsoil being black clay, or, in reality, river mud, to a great depth, with occasional quicksand in the bed of an old watercourse. Experience led Mr. Giles to the conclusion that walls more frequently failed from lateral pressure, and he considered that this indicated a general want of weight. Quantity, as well

[1] Minutes of Proceedings Inst. C.E., vol. xvii. p. 540.

as quality, was necessary. Engineers too often erred, he thought, in not making a wide enough base and in not giving sufficient toe to the walls. Again, trouble, he believed, often arose from unnecessary borings, and where deep bores were needed he made them as far as possible from the difficult part of the work.[1] Mr. Giles was in the habit of employing concrete to a great extent in dock construction, and as early as 1844 passed it to the bottom of the water by means of a movable trunk. Concrete thus laid was taken up ten years later and found so hard that it was only broken with great difficulty. Again, as to cofferdams, he never put in struts at greater distances apart than from 6 feet to 8 feet; and with a pressure of 25 feet to 30 feet head of water the intervals between the struts never exceeded 6 feet. On the question of dock-gates as against caissons he had a decided preference for the former, finding that they worked with greater certainty and rapidity.[2]

Reference may be made to other harbour works. From the Danish Government, for which Mr. Giles carried out new works, including an opening bridge and a graving-dock at Copenhagen, he received the decoration of knighthood of the Order of Danebrog. The opening bridge presents some interesting features, and in a modified form was adopted at Southampton, where the bridge is formed of two leaves running on wheels. "By extending the length of each leaf to about 65 feet, when the bridge was rolled back, it housed itself under a vertebrated platform, which, being made to lift on to the bridge by its own action as the bridge was opened, fell back into its place again as the bridge closed."[3] This is also characteristic of the Copenhagen bridge. Two dry docks at Blackwall were laid out by Mr. Giles in 1864, and harbour and dock works at Cuxhaven in 1870. The latter were suspended owing to the financial panic of 1873; but the works have since been resumed under German engineers upon his plans and are now nearly completed.

During his long life Mr. Giles was engaged upon a variety of matters beside railway and dock work. For instance, as early as 1852 he constructed a new bridge over the Severn at Upton, his design having obtained the first prize in a competition, and in 1865 a large bridge in Austria. He also carried out some drainage works at Dunball, in Somersetshire, and extensive reclamation works and sea-banks on the Solent. He joined the

[1] Minutes of Proceedings Inst. C.E., vols. lv. p. 52, and xcii. p. 168.
[2] *Ibid*, vol. cxi. p. 90. [3] *Ibid*, vol. lvii. p. 53.

Institution in 1846, served on the Council for many years, and was elected President in 1893. He attended the meetings with great regularity and frequently took part in discussions, being always willing to contribute from his experience to the advancement of the profession and to the assistance of his brethren.

Mr. Giles was connected with the Union Steamship Company for many years, having joined the Board in 1857, and was Chairman for eleven years previous to his resignation shortly before his death. He saw the fleet increase from five small ships to the present twenty splendid vessels headed by the "Scot" and the "Norman." His experience of harbour and dock accommodation and the requirements of ocean-going ships enabled him to confer a great benefit upon Southampton and the Company alike by successfully opposing the removal of the Company's headquarters to London. While he was always ready to admit that he owed much to Southampton, that town and its trade are deeply indebted to him.

In 1878 Mr. Giles was elected, on the death of Mr. Russell Gurney, to represent Southampton in Parliament, only to be rejected at the General Election of 1880; but it is worth recording that he was permitted, upon the elevation of Mr. Butt, Q.C., to the Bench, to represent the town again without opposition. He subsequently sat until 1892, when he was defeated, having consented to stand again only a short time before the day of election. He seldom spoke in the House of Commons, and then chiefly upon questions with which he was professionally familiar, when, as might be expected, his opinions were listened to with attention. As a witness before Parliamentary Committees his clear good sense and careful attention to detail made him particularly difficult to cross-examine successfully and caused his opinion to carry great weight. Among the projects supported by him may be mentioned the Preston Docks, the Alexandra Dock at Hull, the Bute Docks and the Manchester Ship Canal.

Regarded with affection by his family and friends, Mr. Giles had the gift of arousing in those closely connected with him an attachment amounting almost to devotion, and even by those towards whom he was compelled to act with severity he was looked upon as a kind and just master. He married in 1838 Jane, the younger daughter of John Coppard, of Hayward's Heath and Hastings, and leaves a large family of daughters and sons. Amongst the latter are Mr. C. T. Giles, M.P., and Mr. George F. L. Giles, Engineer to the Belfast Harbour Commission. Towards the end of 1894 Mr. Giles, in performing a service for a friend, caught a cold, which

turned to jaundice, and, influenza supervening after a few weeks, he gradually sank and died on the 3rd of March, 1895, displaying to the last the patience and courage which had characterized his life.

WILLIAM KILVINGTON was born on the 18th of July, 1852, at Hartlepool, of which town his father held for many years the post of Clerk to the Guardians. He began his career in 1867 as an apprentice at the works of Messrs. Thomas Richardson and Sons, West Hartlepool, where he spent five years in the pattern-shop, erecting-shops and drawing-office. He then attended for a session the College of Physical Science at Newcastle-on-Tyne, devoting himself mainly to the study of physics and mathematics, in which subjects he attained considerable distinction.

Mr. Kilvington's long connection with the North-Eastern Marine Engineering Company commenced in 1873, when he entered its works at Sunderland as a draughtsman. In the following year he was appointed head of the drawing office, of which he had charge until the end of 1882, when he was transferred to the Northumberland Engine Works at Wallsend, the Company's new establishment, as Manager. That post Mr. Kilvington held for nearly thirteen years, having entire control of the works, from which on an average twenty to twenty-five sets of marine-engines were turned out annually, as well as high-pressure pumping-engines for waterworks. He was responsible for upwards of 1,500 workmen and for the design of machinery, for the preparation and signing of specifications, and for estimates of costs for tendering.

Mr. Kilvington died on the 24th of July, 1895, after only a week's illness from inflammation of the bowels. Gifted with natural ability of a high order, he showed great tact in dealing with the ever-recurring labour problems of the day, winning alike the confidence of the workmen and the esteem of the staff, with the members of which he was in constant contact. In addition to his official duties, he was a director of the Walker and Wallsend Union Gas Company, and for many years a member of the Wallsend Local Board. He took great interest in scientific and technical instruction in the Mid-Tyne district, was a member of several scientific bodies, and a Vice-President of the North-East Coast Institution of Engineers and Shipbuilders. In private life he made many friends, being always ready to assist those in need and contributing unobtrusively to several charitable undertakings.

Mr. Kilvington was elected an Associate on the 5th of March, 1878, was subsequently placed among the Associate Members, and was transferred to the class of Member on the 10th of April, 1894.

JOHN LAWSON, born on the 18th of June, 1837, began his engineering career at the early age of fifteen, when he became an assistant to Joseph Locke on the Mantes, Caen and Cherbourg Railway, which afforded direct communication between Paris and the chief naval arsenal of France. On the completion of that line in 1858, young Lawson returned to England and was employed for three years in the London office of Messrs. Locke and Errington. In March, 1861, he proceeded to Bucharest, where he was engaged until the following October in preparing plans for the paving and drainage of that city. Mr. Lawson then remained in Roumania, practising on his own account, until August, 1869, during which time he reported upon railways and on the design and construction of flour-mills and of a factory for agricultural machinery. He was also engaged, under Mr. J. A. Longridge, on the construction and erection, at a cost of £450,000, of twenty iron bridges of an aggregate length of 14,500 feet, to carry over rivers the public highways of Roumania.

During 1869 Mr. Lawson took charge, under Mr. Longridge, of the working of the Fell system on the Mont Cenis Railway, and in the latter part of that year and in 1870 he was actively employed in examining and reporting upon various railway projects in Austria and Hungary. He then had charge from 1871 until March, 1877, as engineer for Messrs. Wythes and Company, the contractors, of the construction of the Franzens Canal, which traverses the districts of Bács in Hungary and shortens considerably the passage between the Theiss and the Danube. The works on that canal, which is 70 miles in length, included the construction of seven locks, all 30 feet in width at sill-level, the shortest being 144 feet long between the gates; of two regulation gates for irrigation purposes; and of numerous bridges. During the same period Mr. Lawson also examined and reported upon the Trieste and Brünn Tramways and the Agram Waterworks in Austria, and upon the Waagthal Railway, the Arad-Szegedin Railway and the Bega Canal in Hungary. He was then employed in 1877 and 1878 on an arbitration case in connection with the Franzens Canal works, and in examining projects for the water-supply of Venice, for the irrigation of Marchegg in Austria,

for a railway in Bavaria, and for the Florida, James River and Kanawha Canals in the United States.

In 1879 Mr. Lawson was engaged as engineer to the "Tramways and General Works" of Bordeaux for the construction of the lines and depots as they stand at present in that city. During the construction and at the time of the transfer of the concession in 1880 to the present Company (Tramways and Omnibus de Bordeaux), he was appointed General Manager, and in that capacity he organised the service and working of the lines. He was Managing Director from 1884 until his death, which took place on the 11th of June, 1895, from Bright's disease. During a portion of the period of his engagement at Bordeaux he also acted as Consulting Engineer to the Calais Tramways Company, pending the construction of its lines.

Mr. Lawson was a practical engineer of considerable ability, who always paid great attention to details in construction. He was possessed of considerable business capacity, was a good linguist, and his management of men, especially of French workmen, was most successful. He was elected an Associate on the 10th of April, 1877, and was transferred to the class of Member on the 30th of April, 1878.

JAMES MACRITCHIE, son of Mr. Alexander MacRitchie, Superintendent Engineer to the Peninsular and Oriental Steamship Company, was born at Southampton on the 26th of September, 1847. After being educated at the Dollar Institution in Scotland and at Edinburgh University, he was trained as an engineer by Messrs. Bell and Miller, of Glasgow. During his pupilage he assisted in the design and construction of the Meadowside Slip Dock, Messrs. Barclay and Curle's Slip Dock, and the Albert Harbour and Esplanade at Greenock; and for the last year he was employed on the Greenock Harbour Works. After the expiration of his pupilage he remained as assistant to Messrs. Bell and Miller, and was engaged on the plans and in superintending the construction of several quays, a coaling-crane, and a railway swing-bridge, in connection with Port Glasgow Harbour.

In January, 1867, Mr. MacRitchie became Assistant Engineer to Messrs. Brassey, Wythes and Aird on the construction of the Calcutta Waterworks. At the end of the following year, owing to ill-health, he returned home and re-entered the service of Messrs.

Bell and Miller, with whom he remained until November, 1869, when he was appointed Resident Engineer on the reconstruction of the Glasgow Suspension Bridges, which he completed in May, 1871. At the same time he superintended the construction of Belmont Bridge over the River Kelvin and the alterations to Bothwell Bridge, both under the direction of Messrs. Bell and Miller.

Mr. MacRitchie was appointed in June, 1871, Assistant Engineer in the Lighthouse Department of the Chinese Government, and in May of the following year to a similar position in the Japanese Lighthouse Department. In 1873 he became Chief Assistant, and three years later Engineer-in-Chief, which appointment he held until 1880, when he returned home, he being the last foreigner in the service of the Japanese Lighthouse Department. In the following year Mr. MacRitchie proceeded to Brazil as Resident Engineer, under Mr. Alfred Rumball, to the City of Santos Improvements Company. In that capacity he designed and constructed a complete system of water-supply, new gasworks, and a line of tramway from the city to the Barra, a resort on the coast. These works he carried out with great skill and ability, although suffering from repeated severe attacks of fever which considerably impaired his health.

In May, 1883, Mr. MacRitchie was appointed Municipal Engineer of Singapore, and took office on the 24th of September in that year. With that appointment, which he held until his death, his name will be particularly associated. His varied experience at home and abroad eminently fitted him for the important improvements and additions which he carried out in the roads, bridges, markets, abattoirs, lighting, water-supply and sanitary arrangements of the municipality, the Commissioners following his advice from first to last with the utmost confidence. The roadways, which are characterised by their excellence and durability, were almost entirely reconstructed by him. There were but two iron bridges in Singapore—Cavanagh Bridge and Elgin Bridge—when he became Municipal Engineer, the others being of timber in a dilapidated condition and unfit for traffic. He therefore directed his attention to their reconstruction, and to the placing of new ones, to give greater facilities for cross-river and cross-canal traffic. These bridges, too numerous to mention in detail, were all designed with the maximum of headway for boats and the minimum of depth consistent with strength. It may be sufficient to state that twenty-three were important structures, beginning with Coleman Bridge and ending with Keppel Road Bridge No. 1, and that many others, chiefly over canals and small

water-ways, are to be found in every direction throughout the municipality.

Mr. MacRitchie's attention was also directed to the improvement and increase of the markets, resulting in the reconstruction of many, and in the erection of several new ones in iron, the Teluk Ayer Market being one of the largest and best in the east. One of his most difficult tasks was the introduction of abattoirs on European principles. Pulau Saigon and Jalan Besar abattoirs —large and well equipped—were completed by him in 1893, but it was not until December of the following year that they were utilised, owing to oriental prejudices, which were not overcome without much diplomacy and ingenuity. The improved lighting of the town also demanded much consideration. Regarding the matter from the standpoint of economy, Mr. MacRitchie advocated improved gas lighting as against electricity, after an exhaustive enquiry, the results of which he embodied in a report to the Commissioners, under whose directions he was experimenting on a large scale with Welsbach burners when he died.

Though deeply interested in all these works, it was to the completion of the water-supply and to the sanitary arrangements of the municipality that Mr. MacRitchie directed his most earnest attention, and he often expressed the wish that he might live to accomplish both. That wish was granted in the case of the water-supply, but his project for the destruction of the refuse and the disposal of the sewage of the town is still in abeyance. When he arrived at Singapore, the population was about 100,000 and the consumption of water 1,400,000 gallons per day; the population is now about 145,000 and the daily water consumption 3,400,000 gallons. He found the reservoir, conduit and canalization inefficient, in bad order, and leaking to the extent of 1,000,000 gallons per day. These he improved and enlarged, using with great success various methods for economising and preventing waste, and finally presented a scheme in 1891 for the enlargement of the impounding reservoir to 650,000,000 gallons, for the purification of the water by filters, for the duplication of the main, and for augmented pumping power to the extent of 336,000 gallons per hour, for which he proposed Worthington engines. All these works were approved by the Commissioners and completed by Mr. MacRitchie in the autumn of 1894, with entire success, notwithstanding perplexing difficulties in the construction of the reservoir-embankments, and just in time to save the town from a water famine, due to prolonged drought and increased requirements.

On the question of the sanitation of the town and the disposal

of its sewage, Mr. MacRitchie presented reports to the Commissioners from time to time, with the view of developing a system best suited to Singapore with its low-lying surface very little above tide-level. In 1892 he was deputed by the Commissioners to make a three months' tour of the chief towns in Burma and India, with the object of reporting upon their sanitation. His examinations were detailed in an exhaustive report,[1] to which he added a scheme for Singapore, advocating the destruction of the town-refuse in furnaces and the manufacture of night-soil into poudrette. To facilitate that, he proposed the division of the town into districts, each having its own destructors and poudrette works, to which latter the night-soil would be conveyed by Shone's pneumatic system.

Mr. MacRitchie's death, which took place on the 26th of April, 1895, was caused by an attack of bronchitis developing into laryngitis and finally into congestion of the brain. That his work and character were highly appreciated by the Municipal Commissioners of Singapore is shown by the following resolution, unanimously passed at a special meeting held on the 6th of May last:—

"That there be recorded in the minutes an expression of the deep regret of the Commissioners at the premature death of Mr. James MacRitchie, who has filled the post of Municipal Engineer since August, 1883, with conspicuous success. That the Commissioners recognise the ability, zeal, and patient attention to detail which characterised all his work, and were gradually winning for him a reputation more than local. That they feel that this Municipality is indebted to him for many public works of vast importance, notably for the bountiful supply of water, and for improved roads and drains; and that had his life been spared, works no less important, which he had carefully designed, would probably have been successfully accomplished. That a copy of the resolution be forwarded to Mrs. MacRitchie, and that she and her sorrowing friends be assured of the sympathy of the Commissioners, of the ratepayers and of the public of Singapore whom her husband long and faithfully served."

The Commissioners have since resolved, as a further proof of their esteem, to place in the Town Hall a bronze medallion, containing his portrait and illustrating the principal municipal works he carried out.

Mr. MacRitchie entered heartily into, and filled a large place in, the social as well as the public life of Singapore. His kindliness and geniality secured a wide circle of friends at home and abroad, and his sound common sense caused his advice to be sought and valued in private as well as in public matters. He was elected an

[1] This report may be consulted in the Library of the Institution.

Associate on the 3rd of February, 1874, was subsequently placed among the Associate Members, and was transferred to the class of Members on the 29th of May, 1883.

THOMAS WILLIAM MILES, eldest son of the late Mr. William Miles of Callinafercy, co. Kerry, Ireland, was born on the 26th of September, 1840. In 1860 he was apprenticed to Mr. William Barrington of Limerick for three years. After about twelve months in the office, he obtained practical experience on the extension of the Waterford and Limerick Railway from Castle Connel to Killaloe, and on the Rathkeale and Newcastle Junction line, under Mr. F. B. Walker, whom he succeeded as Resident Engineer on the latter. He was also in charge, under Mr. Barrington, of the Clodiagh River drainage district in co. Waterford, of the Mulkear River drainage district in co. Tipperary, and of the surveys for the Birdhill and Nenagh and the Limerick and Kerry lines.

In 1868 Mr. Miles entered the service of the Public Works Department of the Government of India as an Assistant Engineer under covenant for five years, at the end of which time he was placed on the permanent establishment. He was first posted to Rajputana, and although his name was borne on the railway staff of the Government, he continued to serve in the General Department of the Rajputana State during the whole of his Indian career, rising in due course to the rank of Superintending Engineer. The energy and devotion he brought to bear on all work entrusted to him soon gained favourable notice from the local Government; and his services were lent by the Government of India to the Jeypore State from April 1873 to July 1878, and to the States of Kotah and Jhallawar from the latter date. While employed in the Jeypore State he carried out successfully some good tank-irrigation projects and new roads, and when he left to take up the engineering charge of the Kotah and Jhallawar States, he was presented by the Jeypore Durbar with a gold watch and chain. He did much good work in the Kotah and Jhallawar States, opening out those hitherto neglected districts by good metalled roads, supplied with numerous masonry bridges or causeways, wherever necessary, over rivers of all kinds. Irrigation, too, was not neglected. He had to depend entirely upon native assistants, and the amount of work he carried out is the best tribute to his energy and professional ability; but what contributed perhaps

in great measure to his success were his active habits, genial disposition and kindness of heart. His sympathy with his fellow-men, whether Europeans or natives, endeared him to all with whom he came in contact. This smoothed over ordinary difficulties and enabled him to succeed where others would often have despaired or failed. He had no enemies and has left many friends.

Exposure, hard work and anxiety, coupled with the climate of Kotah and Jhallawar, obliged Mr. Miles to leave India in December, 1894, and laid the seeds of disease from which he never recovered. He died on the 11th of June, 1895, at the residence of his father-in-law, General J. C. Brooke, in London. Mr. Miles was elected a Member on the 3rd of February, 1880.

JAMES MURDOCH NAPIER, born on the 26th of July, 1823, was a son of the late Mr. David Napier, of Lambeth, well known as an inventor and constructor of printing-machines. In 1837, when but fourteen years of age, young Napier entered his father's works in Lambeth, where he became a skilled workman and draughtsman and soon displayed considerable capacity for original design. He assisted in the construction, in 1841, of the first steam-power gun-finishing machinery used at Woolwich,[1] and, in 1844, of an hydraulic traversing-frame designed by Mr. I. K. Brunel for the Bristol terminus of the Great Western Railway.[2] He then erected for Mr. Brunel an hydraulic travelling-crane in the locomotive works at Swindon and assisted in erecting an hydraulic lift for trucks at Bristol.

In the year 1847, being then twenty-four years of age and having already gained considerable experience, Mr. Napier was taken into partnership by his father, the firm from that time being known under the style of Messrs. David Napier and Son. After spending some months in Spain, directing the erection of gun-finishing machinery, he assisted in 1848 in the design and construction of registering weighing-machines and tipping-trucks for use at Portland breakwater. In 1855 he supplied an elaborate machine for weighing stone at the Tyne works, which not only indicated the weight of the load on the weighbridge, but also registered the gross weight passed over in a given time.

In 1851 the authorities of the Royal Mint began to regard the process of weighing the coin in detail by hand as laborious,

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxvi. p. 347.

[2] *Ibid*, vol. iii. p. 128.

expensive and inaccurate, and the firm of Napier and Son was instructed by Sir John Herschel, then Master of the Mint, to design five automatic coin-weighing machines. The requirements of the Mint involved a complete change in the mechanical arrangement of the machine in use at the Bank of England since 1841, which was due to the invention of Mr. William Cotton, then Governor of the Bank. A description of that automaton balance was furnished to the Institution by Mr. Thomas Oldham.[1] In the course of the discussion upon that Paper Mr. Cotton stated that Mr. David Napier had been "employed to make the machine, and to him was due the suggestion of the two alternating advancing tongues, as well as several other arrangements of the machinery, which he had so successfully constructed." For the Mint Mr. James Murdoch Napier designed and constructed an automatic balance, an illustrated description of which is given in the "Encyclopædia Britannica."[2] That balance divided the coins into three classes, "too light," "too heavy" and "medium," varying between certain given limits, the latter alone being permitted to pass into circulation. From that time he gave much thought to the various processes of coining and their improvement, for which he took out several patents at intervals. In 1853 he designed machinery for the Spanish Mint; in 1861 he spent some months at St. Petersburg making plans for the re-arrangement of the Russian Mint; and in the following year he designed and constructed the "Chancellor" balance for the Royal Mint. In 1870 Mr. Napier was appointed by the Lords Commissioners of the Treasury to visit and report upon European mints, with a view to advise what new machinery would be required if the Mint were removed from its present site. His companions and colleagues in that expedition, which occupied nearly three months, were the Deputy Master, Sir Charles Fremantle, K.C.B., and the Chemist of the Mint, Professor Roberts-Austen, C.B., and the establishments inspected were those of Madrid, Milan, Rome, Constantinople, Vienna, St. Petersburg, Stockholm, Copenhagen, Berlin, Utrecht, Brussels and Paris. A copy of Mr. Napier's Report may be consulted in the Library of the Institution.[3] In 1877 he designed and constructed the "Lord Chief Justice" bullion balance for the Bank of England and a mercurial gauge for indicating speed up to 400 revolutions per minute, used with it. He also devised,

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[1] Minutes of Proceedings Inst. C.E., vol. ii. (1843) p. 121; and "Ure's Dictionary of Arts, Manufactures and Mines," vol. i. p. 282.

[2] Ninth edition, vol. xvi. p. 490.

[3] Tracts 8vo., vol. 363.

for use in the Indian mints, a beautiful machine which first ascertains how much it is necessary to cut from each blank piece in order to reduce it to the standard weight, and then removes the necessary amount of metal and no more.[1]

Another matter to which Mr. Napier devoted considerable attention was the printing of bank-notes. In July, 1853, he took out a patent for improvements in letter-press and other raised-surface printing-machines,[2] and in the following year he designed and constructed a machine for printing the Bank of England notes. The feature of that press was a platen with contrivances for both the tables and the inking-rollers to traverse, by which means an effect was produced equivalent to rolling with a single hand-roller twenty different times. The form of every note was made to one gauge, and every denomination had its separate tympan and overlaying. By those means, when a note-plate was once made ready for press with its overlaying, it was always ready at a moment's notice for taking impressions. At each end of the press were counting-machines, so that no impression could be taken without being registered, the rate of printing being 3,000 notes per hour.[3] This was at the time of the substitution for the copper-plate printing—until then employed at the Bank—of surface-printing from electrotypes, a much more rapid process and one which does not require damping. In 1857 Mr. Napier took out two patents for further improvements in printing-machines,[4] and he continued throughout his life to give much thought to that branch of mechanics, taking part no less than thirty years later in a discussion on the subject at the Institution.[5]

Mr. Napier's brain, however, was far too active to confine itself to automatic balances and printing machinery. The list of inventions for which he was responsible is too long to be given in detail; but the variety and wide range of the subjects which occupied his mind may be gathered from the fact that the patents he took out included registering tide-gauges, mariners' compasses, barometers, machinery for producing cold the lead bullets for the Government rifles instead of cast bullets, an apparatus for paying out submarine telegraph cables, machinery for the manufacture of soda, speed indicators and governors, and numerous smaller matters.

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[1] "Encyclopædia Britannica," ninth edition, vol. xvi. p. 489.

[2] Patent Office, Abridgments of Specifications, Printing, 1533–1857, p. 370.

[3] Journal of the Society of Arts, 1854–55, p. 86.

[4] Patent Office, Abridgments of Specifications, Printing, 1533–1857, pp. 602, 610.

[5] Minutes of Proceedings Inst. C.E., vol. lxxxix. p. 278.

Mr. Napier died at his residence adjoining the works in Lambeth on the 23rd of March, 1895, at the age of seventy-one, death being due to an affection of the throat. Springing from a family of engineers, he did much to maintain and increase the reputation of the name he bore. He was elected a Member on the 2nd of December, 1884.

JAMES CRAWFORD PARK was born in Liverpool on the 1st of July, 1838. In 1856 he entered the locomotive works of the London and North Western Railway Company at Crewe. After serving his time as an apprentice he remained engaged in the drawing office until 1866, in which year he left Crewe and took charge of the drawing office of the Great Northern Railway at Doncaster, at first under Mr. Sturrock and subsequently under Mr. Patrick Stirling, Locomotive Superintendents. In 1873 he was transferred to the Company's New England Works at Peterborough, at which place he remained as Assistant Shop-Manager until his appointment as Locomotive Superintendent to the Great Northern Railway of Ireland in January, 1881. From that time until his death Mr. Park had charge of all the locomotives, carriages, wagons and rolling-stock of this line, 523 miles in length.

The Great Northern Railway of Ireland consists of several lines amalgamated together, or purchased under agreement, each of which possessed rolling-stock of its own special description. Great care and organisation were required to work to the best advantage this mixed stock, which varied considerably. New and more suitable stock had to be added every year. Many of these engines, carriages and wagons were constructed from Mr. Park's designs in the Company's works at Dundalk, and others were obtained from builders elsewhere. All the repairs of engines and rolling-stock were effected at Dundalk, or at the branch works in Belfast, Dublin, and Londonderry. Mr. Park designed and constructed several handsome saloon-, drawing-room, and dining-cars.

For some months before his death Mr. Park was afflicted with a serious internal complaint, which rapidly assumed an aggravated form and terminated fatally on the 27th of May, 1895. He was most energetic and took a deep interest in his duties to the last. He was elected a Member on the 3rd of May, 1887.

OWEN CHARLES DALHOUSIE ROSS, third son of Mr. Edward Dalhousie Ross, was born at St. Germain, near Paris, on the 8th of January, 1823. After being educated at Heidelberg and at Darmstadt, he became a pupil of Mr. Edward Oliver Manby, a younger brother of Charles Manby, in June, 1841. Two years later he was removed to the Paris office of John and Edward Manby; and in 1844 he went to Spain, where he was engaged for three years as an assistant engineer at the works and mines of the Asturian Iron Company and on railway construction in Andalucia.

In the spring of 1847 Mr. Ross was again in England, and for the following three years he was engaged on various railway works at home. During a brief visit to Paris in the early part of 1848 he witnessed the second French revolution and the flight of Louis Philippe. In 1851 he returned to Spain as Resident Engineer on the Madrid and Alicante Railway, the first of the great trunk lines constructed in that country, and for two years and a half had charge of the execution of the works on a division of 35 miles of that line. On the completion of that undertaking he was occupied for some years, in conjunction with his brother, the late Mr. Henry Francis Ross, on the surveys for several hundred miles of railway in different parts of Spain—from Aranjuez to Cuença (100 miles), Castillejo to Toledo (17 miles), Almorchon to the coal-fields of Belmez (40 miles), Belmez to Cordova (45 miles), Rivadeo (a port in the Bay of Biscay) to Lugo (65 miles), and thence to Monforte (62 miles); all of which required careful study, as they traversed much rough country, such as the Sierra Morena and the Cantabrian Mountains. With the exception of the branch from Rivadeo to Lugo, these lines have since been constructed and are now open to traffic.[1] From 1862 to 1866 Mr. Ross was in charge of the execution of the works of the Utrera-Moron and the Utrera-Osuna railways in Andalucia, and he was subsequently engaged on the construction of the lines between Seville and Cordova *viâ* Ecija, and between Seville and Malaga *viâ* La Roda. He was also in practice on his own account in Madrid, and constructed tramways in that city from the Puerto del Sol to the Fuente Castellana, and obtained a concession for the "Mataderos" (slaughter-house and market), afterwards erected by the late Mr. George B. Crawley, contractor.

In 1868 Mr. Ross was in London busily engaged in working out the details for, and in projecting, a deep-sea cable from England

[1] Minutes of Proceedings Inst. C.E., vol. cxvi. p. 384.

to Bombay, *viâ* Gibraltar, Malta, Alexandria, the Red Sea and Aden. The original Red Sea cable having failed in 1860, the only means of telegraphic communication between England and India was *viâ* Constantinople and the Persian Gulf, and in their transit through various foreign countries messages were frequently delayed and inaccurately repeated. It was most desirable, therefore, to lay down an entirely English line, under one management and control. He spent much time on this project, which, however, the India Office declined to take up.

Mr. Ross's connection with Spain was renewed in 1870 under circumstances which proved most unfortunate for him. In July of that year he purchased the Hellin sulphur mines in the province of Murcia and formed an English company to work them. For a year and a half he was in Spain endeavouring to work those mines, but his efforts were unsuccessful and the capital he had thus embarked was practically lost. He returned to England and from that time failed to obtain remunerative engineering employment. He devoted himself to the prosecution of various inventions and to such literary work as he could obtain, and indeed for the last twenty years of his life may be said to have had a hard struggle for bare existence. In 1874 he published a short work in which, in view of the possible exhaustion of the coal-fields of Great Britain, he advocated the utilization of petroleum and other mineral oils as fuel and as gas.[1] After a series of experiments commenced in the autumn of 1881, Mr. Ross produced a primary battery—which he called his "water battery" —capable of generating electric energy without the use of steam-engines, dynamos or accumulators. A full description of this invention may be found in a pamphlet entitled "The Ross Primary Battery," which is preserved in the Library of the Institution.[2] He devoted many years to this subject and in 1889 patented a nitrate battery, from which the zinc could be recovered and the nitrate solution, after it had done duty in the battery, could be used for the fertilisation of land.[3] He also wrote a popular lecture on "The Three Allied Forces: Chemical Affinity, Electricity, and Magnetism,"[4] which contained some original views and suggestions interesting to the student of electricity. Among his miscellaneous writings are pamphlets entitled "Spain and the War with Morocco,"[5] "The Depression in Agriculture and

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[1] "Air as Fuel; or, Petroleum and other Mineral Oils utilized by Carburetting Air and rendering it Inflammable." London, 1874. E. & F. N. Spon.

[2] Tracts 8vo., vol. 437.

[3] *Ibid*, vol. 517.

[4] *Ibid*, vol. 493.

[5] *Ibid*, vol. 178.

Trade,"[1] and "Reminiscences of Grattan's Parliament."[2] To the Institution he presented in 1875 a Paper on "Petroleum and other Mineral Oils applied to the Manufacture of Gas,"[3] and for many years he was a constant and valued contributor to Section III. of the Minutes of Proceedings devoted to abstracts of articles appearing in foreign Transactions and periodicals. The inventions for which he from time to time took out patents embraced a wide range, including the utilization of petroleum as fuel, the separation of sulphur from ores, refrigerating apparatus for railway-carriages, galvanic batteries, electric lamps for mines, and the utilization of waste products from electrical batteries.

In 1894 Mr. Ross was busy with an ingenious idea for a boiler, which, owing to its large heating-surface, he thought might effect great economy of fuel. In January, 1895, just after he had prepared the specification and taken out a provisional patent for this invention, he was struck down with paralysis, from which he never completely recovered. As soon as he got a little better his thoughts went back to his boiler, for the invention had to be completed and put into workable shape. He was powerless, however, to make drawings or to explain his meaning, and there is no doubt that the anxiety and worry of this matter hastened his death. He went to St. Leonards-on-Sea, where he suffered a second seizure in the street and died on the 24th of June, 1895, without regaining consciousness.

A well-educated and accomplished gentleman, Mr. Ross unfortunately spent the latter part of his life in the pursuit of ideas, phantoms which could never be realized. He bore his losses, however, and the persistent bad fortune of his latter years, with a courage and dignity which inspired admiration and respect. As a friend he was amiable and true, and the variety of his knowledge and the neat way in which it was stored in his brain made him a most interesting and instructive companion. He was elected an Associate on the 29th of June, 1847, and was transferred to the class of Member on the 19th of May, 1868.

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[1] Tracts 8vo., vol. 434. [2] *Ibid*, vol. 434.

[3] Minutes of Proceedings Inst. C.E., vol. xl. p. 150.

JOHN CHALONER SMITH, eldest son of Mr. John Smith, a Proctor of the Irish Ecclesiastical Courts, was born in Dublin at St. Stephen's Green on the 19th of August, 1827. He was educated at Trinity College, Dublin, after which he became a pupil of the late Mr. George Willoughby Hemans, by whom, on the expiration of his pupilage, he was appointed Resident Engineer of the Waterford and Limerick Railway on the 5th of December, 1853. Four years later he became Engineer of the Waterford and Kilkenny Railway, which post he held until that line was amalgamated with the Waterford and Limerick in 1861, when he resigned to enter into partnership with the late Mr. John Bagnell, as railway contractors. This partnership proved a great financial success, Messrs. Smith and Bagnell constructing several railways, including the Borris and Ballywilliam, the Clara and Streamstown, and the Roscrea and Birdhill, as well as many other large works.

On the 27th of February, 1868, Mr. Smith, having previously retired from railway contracting, was appointed Engineer of the Dublin, Wicklow and Wexford Railway, Messrs. Cotton and Flemyng, by whom nearly all the new works were then being constructed, being Consulting Engineers to the Company. Subsequently Mr. Smith became Chief Engineer, and during the thirty years of his connection with that Company he carried out several important works, including the construction of the New Ross extension, a line about 18 miles in length, involving rock-cutting 3 miles long of an average depth of 40 feet, a tunnel of 740 yards, and a bridge over the River Barrow; also the re-modelling and doubling of the line between Kingstown and Dalkey, and the reconstruction and enlargement of the Westland Row terminus.

Mr. Smith and Mr. W. H. Mills, Engineer-in-Chief of the Great Northern Railway of Ireland, were joint Engineers in the construction of the loop line connecting the Westland Row and Amiens Street termini—an undertaking which involved some heavy and complicated bridge-work in the crossing of streets and river. This line had been proposed by Mr. Smith twelve years before the Act of Parliament was obtained, and he never for a moment ceased fighting in its favour until he was successful in getting the Act passed in 1884. It was made under a Joint Committee (and Guarantee) composed of Directors of the Dublin, Wicklow and Wexford Railway, the Great Northern Railway of Ireland, and the City of Dublin Steam Packet Company, and is an

important line for the maintenance of through communication between Kingstown, Queenstown and America.

During the latter years of his life Mr. Smith suffered very much from defective eyesight and was obliged to undergo an operation for cataract. He retired about a year before his death, which took place on the 13th of March, 1895, from *angina pectoris*.

Mr. Smith was a man of culture and ability, and a good judge of engravings, especially mezzotintos, on which the authorities of the British Museum occasionally sought his opinion. He succeeded in getting together an extremely fine collection of mezzotintos. A few years ago, when the Dublin National Library and Museum Buildings were about to be furnished, Mr. Smith offered his entire collection to the Government of the day for a sum of £7,000, but the Treasury could not see their way to purchase it. A much larger sum was realized for two portions of the collection sold by auction. Owing to the munificent gift of £1,000 by Sir Edward Cecil Guinness, Bart. (now Lord Iveagh), some exquisite specimens were purchased at those sales for the Dublin National Gallery. Mr. Smith published a work on English mezzotinto portraits which is considered a standard authority by collectors.[1]

Of late years he took great interest in the financial relations between Great Britain and Ireland, and gave important evidence before the Royal Commission on that subject now sitting. He was a most active member of the Institution of Civil Engineers of Ireland, of which he was for fourteen years Honorary Secretary, and President in 1893 and 1894. Mr. Smith had a pleasant, genial manner, was particularly kind and encouraging to his assistants, and was always anxious to recognise ability wherever he found it. His loss will be keenly felt by many charitable bodies. He was elected a Member of the Institution on the 14th of January, 1862.

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[1] "British Mezzotinto Portraits," 4 vols. 8vo. London, 1871–82.

WILLIAM WAINWRIGHT was born at Leeds on the 2nd of August, 1833, and served an apprenticeship of seven years at the works of Messrs. E. B. Wilson and Company, engineers, of that city. In 1854 he entered the service of the Oxford, Worcester and Wolverhampton Railway Company. His ability was soon recognised and he rapidly rose to the position of foreman, and, in 1860, to that of Superintendent of the Locomotive and Carriage Department. Upon the amalgamation of that line with the Great Western Railway Company in 1863, he was appointed Superintendent of the Locomotive and Carriage Department for the Worcester division, which post he held for ten years. Mr. Wainwright left the service of the Great Western Railway Company in 1873 and for nearly five years was Manager of the Worcester Carriage and Wagon Company, in which capacity he was responsible for the construction of large quantities of rolling-stock for many of the principal railways in England and abroad, and also of bridges and agricultural machinery. In January, 1877, however, he returned to his old work as Chief Out-door Assistant of the Carriage and Wagon Department of the Midland Railway. During the five years he was at Derby he had charge of some 1,500 men.

Mr. Wainwright's connection with the South Eastern Railway began in April, 1882, when he was appointed Chief Carriage and Wagon Superintendent to that Company. That post he held for thirteen years, during which period he partially revolutionized the coaches on that system, bringing them up to modern requirements. Perhaps the best type of coach designed by him is the combined family and invalid carriage, which has been highly approved by the medical profession. He also introduced some excellent saloon cars, and under his management gas took the place to a great extent of oil-lamps.

Mr. Wainwright suffered for some years from bronchial affection. In the spring of 1895 he spent two months at Falmouth, from which place he returned to Ashford apparently much improved in health. He resumed his usual duties, but unfortunately took a chill which, rapidly developing into acute pneumonia, proved fatal on the 21st of May, after only two days' illness. Mr. Wainwright's career is sufficient indication of his ability as an engineer. In disposition he was methodical, straightforward and amiable; and, whilst serving his employers with zeal, he was equally careful to be just and considerate to those under him. He was elected a Member of the Institution on the 24th of May, 1887.

ARTHUR MELLEN WELLINGTON[1] was born in Waltham, Mass., U.S.A., on the 20th of December, 1847. He was descended on his father's side from an old New England family, which had resided on a rocky hillside farm in the town of Lexington, Mass., since the time of the early colonists. He graduated at the Boston Latin School, and then, when only sixteen years old, began to study the profession by apprenticeship to a practising engineer. From 1863 to 1866 he was an articled pupil in the office of Mr. John B. Henck, of Boston, well known to engineers as the author of "Henck's Field-Book." His first work after leaving Mr. Henck's office was an engagement in the engineering corps of the Brooklyn Park Department, under Mr. Frederick Law Olmstead, where he served as leveller and assistant engineer. In 1868 he obtained his first post on railway work, a field in which he was to win enduring fame. This was on the Blue Ridge Railroad in South Carolina, where he remained for a year as transitman, having charge of a locating party. He then went to the Dutchess and Columbia Railroad in New York and for nearly a year served on that line as an assistant engineer. In 1870, when twenty-three years of age, he was placed in charge of a division of the Buffalo, New York and Philadelphia Railroad, and, notwithstanding his youth, he was soon advanced to the position of Principal Assistant. After remaining with that Company two-and-a-half years, he became locating engineer of the Michigan Midland Railroad, and later was Engineer-in-Charge of the Toledo, Canada Southern and Detroit Railroad.

The panic years of 1873–74 put a sudden stop to railway construction, and Mr. Wellington, in common with hundreds of other engineers, found his occupation gone and no demand for his services in any new position. In his application for membership of the American Society of Civil Engineers, made in 1881, he said: "1874–78, was engaged in miscellaneous professional, business and literary occupations more interesting than lucrative, and not always particularly interesting." In later years, however, he was accustomed to refer to this period of enforced idleness—so far as idleness was possible to a man of his restless energy—as a blessing in disguise. Hard as it was for the young engineer to leave the professional work in which he was intensely interested and making satisfactory advancement, it caused him to use his enforced leisure for the study of the broader problems in con-

[1] This Notice has been abridged, with some modifications, from an article which appeared in the *Engineering News* of New York, 23 May, 1895.

nection with the profession and to lay the foundations for the more important work of the later years of his life.

Mr. Wellington's first literary venture was made in 1874, when he was only twenty-seven years of age. It was "The Computation from Diagrams of Railway Earthwork," a book which was the outcome of the methods he had worked out for expediting his computations on the railways on which he was engaged. This book was very favourably received, and in the intervals during the years 1874–78, when other occupations failed him, it was natural that he should again turn his attention in the direction of contributing to the literature of the profession, and upon the subject in which he had had the most experience—railway location. His great work, and that by which his fame as an engineer was firmly established, "The Economic Theory of the Location of Railways," was begun in 1875, as a few notes in preparation for an anticipated location. It was afterwards expanded into a magazine article and was first published in the *Railroad Gazette* in the latter part of 1876, as a series of articles on "The Justifiable Expenditure for Improvements in Railway Alignment." These articles were reprinted in book-form in 1877, and the attention of engineers and railway men was at once attracted to their writer as an engineer of uncommon brilliancy and ability.[1]

In 1878 Mr. Wellington accepted the position of Principal Assistant to Mr. Charles Latimer, Chief Engineer of the New York, Pennsylvania and Ohio Railway. His duties there were, from one point of view, less to his taste than the work of railway location; nevertheless, the three years spent on that line gave him an opportunity of gaining experience in railway operating details and of acquiring a fund of information, of which at a later date he made good use.

In the summer of 1878, through the courtesy of Mr. Charles Paine, then Chief Engineer and General Manager of the Lake Shore and Michigan Southern Railway, Mr. Wellington carried out an extended series of experiments on the resistance of rolling-stock, the results of which were presented in a paper read before the American Society of Civil Engineers on the 15th of January, 1879. Those experiments were made chiefly by dropping cars down a known grade, and had much influence in establishing formulas for train-resistance at low velocities. In the following winter he carried out a series of tests on journal friction at low

[1] This work, as well as that on "The Computation of Earthwork from Diagrams," may be found in the Library of the Institution.

velocities, the results of which, however, were not made public until 1884, when they were embodied in a paper read by him before the American Society of Civil Engineers. It is an excellent illustration of the thoroughness and absorbing interest with which he undertook the solution of any engineering problem, that having made the train-resistance tests above noted and finding in the results some elements of uncertainty, he carried out in the little leisure which his regular duties gave him a further elaborate series of tests to settle the doubtful points.

After spending three years on the New York, Pennsylvania and Ohio Railway, Mr. Wellington accepted in March, 1881, the post of Engineer-in-Charge of Location and Surveys on the Mexican National Railway. Some of the most interesting portions of his work on that line were described in a Paper read by him before the American Society of Civil Engineers in July, 1886. During the three years 1881–84 he remained in Mexico, first in the service of the Mexican National Railway, and later as Assistant General Manager and Chief Engineer-in-Charge of the Location of the Mexican Central Railway, under Mr. Rudolph Fink.

But the work of railway location, congenial as it was, Mr. Wellington was soon to exchange for an occupation still better suited to his taste. In 1884 he returned to the United States and entered the field of technical journalism, becoming one of the editors of the *Railroad Gazette*. His experience in writing books, and as a contributor to various journals, had already familiarised him with literary work and had revealed an exceptional talent for it, and he entered upon this new field of labour with a zeal and ability which at once attracted attention. While upon the staff of the *Railroad Gazette*, he edited the revised edition of the "Car-Builders' Dictionary," and his leisure was devoted to preparing for the press the second edition of his work on "Railway Location," which was finally published in the spring of 1887. The value of this work had been well proved by the demand for it: the first edition was soon exhausted and the price for second-hand copies rose higher and higher until as much as $20 was paid for a single copy.

In January, 1887, Mr. Wellington transferred his services to *Engineering News* as one of the editors in chief and part owner. The influence of his energy was at once seen in every department. In his editorial work he combined in wonderful measure the valuable qualities of industry and originality, for which he was conspicuous. If he edited a letter for publication in the correspondence column, it was sure to suggest some idea

to him which he would add as editorial comment. If he prepared a note for the "Engineering News" page, it was seldom a colourless recital; some piquant criticism would be thrown in. His industry was measureless; he never dropped a proposed scheme merely on account of the amount of labour involved, but seemed to regard it rather as a sort of challenge and undertook it with the greater relish.

Mr. Wellington found time during the years following 1887 for occasional service as a Consulting Engineer. Among the more important works on which he gave advice were the elimination of grade crossings at Buffalo, the improvement of railway terminals at Toronto, and the foundations of the Board of Trade Building in that city. In the summer of 1888 he made an extended examination of the Canadian Pacific Railway system, and later gave expert testimony in the suit between that company and the Canadian Government, in which the character of the construction taken over by the Company was in question. He was a member of the Board of Engineers which examined and approved the estimates of the Nicaragua Canal Company in 1890. In 1893 he was called before the Massachusetts legislature with reference to the proposed invasion of Boston Common by the West End Street Railway, and at his suggestion the Tremont Street subway, now under construction by the city, was decided upon as the best plan for effecting the desired improvement. The last work which he undertook as a Consulting Engineer was the improvement of the railway lines in the Island of Jamaica, where he spent two months in the spring of 1893.

Reference has already been made to Mr. Wellington's contributions at different times to the Transactions of the American Society of Civil Engineers. He became a Member of that Society in 1881, and was always among its most enthusiastic supporters. At later dates he was elected to membership in the American Society of Mechanical Engineers, the Canadian Society of Civil Engineers and the Engineers' Club of New York City.

In the summer of 1892 Mr. Wellington took a vacation of three weeks, but instead of leaving the city, as was his usual custom, he devoted his leisure to working out some ideas in thermodynamics which had occurred to him years before. It was characteristic indeed of the man and of his innate love for work that he chose to spend his leisure in such a manner, rather than in pleasure-seeking of the ordinary sort. The result of his study was the invention of an entirely new type of thermodynamic engine, designed to convert heat into mechanical work with a much smaller percentage

of loss than the best existing steam-engines. Henceforward the development of his invention became the all-absorbing work of his life, and in his earnestness and zeal all thought of care for his health was forgotten. It had always been his habit to work far into the night when the hours of the day were not sufficient, but in his labours upon this latest child of his brain, his eagerness was such that he was no longer able to turn his thoughts away from it, even in the few hours which he allowed himself for rest. Even his iron constitution could not bear up under such a strain, and early in 1894 he found himself physically unable to go on with his work. Entire rest brought temporary relief, but not, unfortunately, the restoration to a healthy condition of the over-taxed organism. During the eighteen months from the first conception of his invention until the failure of his health, Mr. Wellington's contributions to the columns of *Engineering News* became less frequent, until they ceased entirely in May, 1894. He had at that time completed his invention and had made good progress in experiments as to its practical and commercial development. How great a trial it was to drop work upon it, when so near completion, only those closest to him could realize; but the sanguine and resourceful temperament which had been his stay in every disappointment was evident here, and he made preparations for the European trip which his physicians advised, with the same good humour as if it were a mere pleasure journey and in entire accord with his inclinations.

While travelling in Norway in August, 1894, Mr. Wellington's disease suddenly assumed an acute form, and serious hæmorrhage of the kidneys occurred, so persistent as to threaten an immediate fatal termination. It was at length arrested, however, and in September he was sufficiently improved in health to return to the United States. His malady was a rare and peculiar one, baffling the physician's skill. A period of several weeks, in which he would apparently make steady progress towards restored health, would be followed by a sudden return of hæmorrhage and a loss of more ground than had been gained. Such alternations are even more calculated to depress the spirit than a steady downward progress; but all through these trying months Mr. Wellington's sanguine cheerfulness never failed. On the 15th of May, 1895, an operation for the removal of the diseased kidney was performed with success. But, besides the disease at this point, there was a chronic weakness of the heart, and at 9.30 P.M. on the following day that organ refused to perform its work.

Mr. Wellington was by nature a man of intense convictions, his

standard of right was high, and compromise with anything which did not reach that standard was always difficult for him to make. In every cause that appealed to his interest, his inclination was always to espouse whichever side he believed to be right and to labour ardently for its success. With such a temperament, it was natural that he should occasionally make enemies, especially among those who knew little or nothing of him personally and could not therefore understand that no real malice lay behind the quick, cutting remark, the caustic comment or the keen satire from his pen. But to those whose privilege it was to know him intimately, the good-heartedness of the man was always evident.

Mr. Wellington was elected a Member of the Institution on the 5th of February, 1889.

JOHN DOUGLAS ORMOND BRIDGES, eldest son of Mr. John George Bridges, of Mead House, Epsom, was born on the 12th of October, 1866. He was educated at Rossall School, Lancashire, and at King's College, London, where he went through a three years' course in the Applied Sciences Department. In the spring of 1886 he proceeded to Canada in the hope that the Dominion would afford wider scope for his energy than the old country. He soon found work as a draughtsman in the Engineer's office of the Northern and North Western Railways (now part of the Grand Trunk System), where he remained for about eight months. In July, 1887, he was appointed a Sectional Engineer on the Atlantic and North Western Railway, since amalgamated with the Canadian Pacific line.

At the end of 1888 Mr. Bridges proceeded to South America to take up the post of Sectional Engineer on the Buenos Ayres division of the Central Argentine Railway. He remained in the service of that Company until his death on the 17th of May, 1895, from typhoid fever, contracted, it is believed, while carrying out some drainage works. His untimely end, at the early age of twenty-eight, was much regretted by the management of the Central Argentine Railway Company, by which he was regarded as an excellent officer, and by a large number of friends among whom his amiable disposition and many good qualities made him a great favourite. He was elected an Associate Member on the 3rd of May, 1892.

LINDSAY BURNET, second son of Mr. John Burnet, well known as an architect in Glasgow, was born in that city on the 5th of November, 1855. In 1871 he was apprenticed to Messrs. Barclay, Curle & Co., engineers, of Glasgow. After remaining two years with that firm, he went through the pattern-shops and drawing-office of Messrs. Thomas Wingate & Co. at Whiteinch, and then, in order to enlarge his experience, spent some months at sea in 1876 as fourth engineer on the British India Steam Navigation Company's s.s. "Assyria." Mr. Burnet was next for a time in the employment of the late Mr. W. F. Batho in Westminster and subsequently attended for eighteen months the engineering classes of Professor Kennedy at University College. He then assisted in the erection of marine-engine works for Messrs. Ramage and Ferguson, at Leith.

In 1883 Mr. Burnet started in business on his own account in Glasgow. He designed and erected the Moore Park Boiler Works at Govan, where he showed much judgment and skill in laying down machinery and tools for the purpose, to which he constantly adhered, of turning out work of the best description. He was joined in 1887 by Mr. Sinclair Couper, the style of the firm continuing, however, as Lindsay Burnet & Co. Mr. Burnet was not only a specialist in the design and manufacture of steam-boilers; he devoted much attention to all matters connected with steam engineering and made a special study of the combustion of coal and other fuels, of the analysis of water, of the various fuels and of the waste products of combustion. He gave very close attention also to the best means of dealing with different qualities of water, to the most efficient methods of stoking and burning fuel, and to the question of smoke abatement. His services were in frequent request as an arbiter and expert, in which capacity he displayed the thoroughness and enthusiasm, the close and painstaking attention, which characterised all his work. His amiable disposition endeared him to all with whom he came into contact, while his relations with those whom he employed, whose best interests he had at heart, were always of the most cordial nature.

Mr. Burnet's health, however, was latterly not robust, and, in December, 1894, a chill settled on his lungs. He was recovering and making arrangements for a voyage to Madeira, when he was attacked by influenza, to which he succumbed on the 14th of March, 1895, at the age of thirty-nine. Mr. Burnet was a Member of the Institution of Mechanical Engineers, of the Institution of Naval Architects, of the Philosophical Society of Glasgow, and at

the time of his death was serving on the Council of the Institution of Engineers and Shipbuilders in Scotland. He was elected an Associate Member on the 31st of May, 1881, having previously, as a Student, received a Miller Prize for a Paper entitled "Description of a Cargo-Carrying Coasting Steam Ship, with detailed investigation as to its efficiency," which was considered of sufficient merit to be printed by the Institution.[1]

FITZHERBERT RUXTON DESPARD was born in co. Meath, Ireland, on the 2nd of January, 1841. His father, a member of an old and respected family, long resident in Queen's Co., had been in the army and at that time was a Government Magistrate. Young Despard was educated at Portarlington School, on leaving which he became a pupil in the office of the late Mr. Nathaniel Beardmore, with whom his brother, Mr. Richard Carden Despard, was in partnership. About the year 1861 he emigrated to Vancouver Island, where he became engaged in gold mining and went to the Caraboo Mines, situated in a remote district, difficult of access, owing to the uncivilized condition of the intervening country. This speculation at first proved a great success, but afterwards failed. From Caraboo he wandered southwards along the West Coast of America, and visited the Sandwich Islands, eventually being employed by a contractor to superintend the carrying out of some harbour works on that coast. That contractor failing to meet his engagements, Mr. Despard again migrated, this time northwards. After many hardships and perils he found work in laying out the pioneer track of the first railway across the prairies to the Rocky Mountains. Whilst so occupied, he and his companions were surrounded by the Black Feet Indians and barely succeeded in saving their scalps, after a running fight of many hours, when, under the guidance of an old prairie hunter, they reached settled territory. On the completion of that work he proceeded to Canada, where he accepted the post of Secretary to a Fire Insurance Company, but a great fire having placed the Company in difficulties, it was wound up, and he returned to England in 1882.

In March, 1883, Mr. Despard was successful in obtaining the responsible post of manager to the Kimberley Waterworks

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[1] Minutes of Proceedings Inst. C.E., vol. lxvi. p. 363.

Company. In that capacity he carried out several extensions of the works, the Company, under his management, attaining a high state of prosperity. He resigned this appointment in December, 1889, and returned to London. There he became acquainted with the agent of the Companhia de Moçambique and assisted in carrying out the negotiations for the concession for the Beira Railway. Eventually he proceeded to Beira in the capacity of Treasurer General under the Moçambique Company. There he remained for some years, much against the wishes of his friends. He died of typhoid fever on the 15th of March, 1895, after a few days' illness, deeply regretted by all the inhabitants of Beira as well as by his many friends in South Africa. Mr. Despard was elected an Associate Member on the 5th of February, 1884.

WILLIAM HENRY GRAHAME was born on the 3rd of April, 1858. After serving an apprenticeship to a mechanical engineer, he entered in 1879 the service of the Public Works Department of New Zealand as a draughtsman and computer. He was next engaged, from 1882 to 1885, in assisting Mr. Alfred Atkins in the design and construction of railway, road and bridge work in that colony, and then acted for about twelve months as contractor's agent on the Wellington-Manawatu Railway.

In January, 1887, Mr. Grahame was placed in charge, by the contractors, of the construction of a short section of the New Zealand Midland Railway, and in April, 1889, he was appointed an Assistant Engineer on the Company's staff. In that capacity he remained until 1894, when the cessation of the works necessitated a reduction of the staff. Mr. Grahame then proceeded to Wellington, but unfortunately found much difficulty in obtaining work. After undergoing considerable privation he ultimately secured employment as a draughtsman in the office of Mr. William Ferguson, engineer to the Wellington Harbour Board. His health, however, never very good, had broken down, and on the 8th of May, 1895, he died at Wellington from an acute attack of erysipelas. Mr. Grahame was elected an Associate Member on the 1st of December, 1891.

JOHN BENJAMIN McCREA, born on the 28th of September, 1833, served a pupilage of five years to Messrs. McCormick, Greene & King, contractors. For that firm in charge of the construction of the Londonderry and Enniskillen Railway; the Staines, Wokingham and Woking Junction line; the section from Newbliss to Enniskillen of the North Western Railway of Ireland; the Banbridge, Lisburn and Belfast line; the Dublin and Antrim Junction Railway; and the Dublin Waterworks.

In 1868 Mr. McCrea entered the service of Messrs. Thomas Monk & Company (now Messrs. Monk and Newell), contractors, of Liverpool. During the twenty years of his connection with that firm he had charge of the construction of many important undertakings, including the extension of the Rivington Waterworks for the Liverpool Corporation (1868–71); the Canada and Huskisson Docks for the Mersey Trust (1871–72); the Belfast District Sewerage Works (1872–77); a new engine-shed and the shortening of Dingle Tunnel for the Cheshire Lines Committee (1877–80); the Witham Outfall Works (1880–86); and the Cashen Drainage Works (1886–88).

In connection with the works carried out by Mr. McCrea at Belfast between 1872 and 1877 it may be mentioned that there were special contracts for the Antrim Road and the Windsor Districts sewers. The latter were constructed to a large extent in tunnel, while the chief feature of interest in the Antrim Road sewers was the crossing in open cutting of the Northern Counties Railway terminus, which was in bad ground, without interference to the large passenger and goods traffic of that line. The Witham Outfall works, upon which Mr. McCrea was engaged between 1880 and 1886, comprised the formation of a new channel from the sea to Boston, with an average bottom width of 115 feet, the excavation amounting to 2,000,000 cubic yards; and the formation of an embankment across the old river, whereby the distance from Boston to the sea was shortened by about 5 miles and an increase of 8 feet in depth was given to the channel.[1]

Mr. McCrea retired from active work at the end of 1888. Two years later he settled at Belfast, where he lived until his death on the 27th of March, 1895. As an engineer he was able and reliable, the works entrusted to his charge being carried out with skill and exactness, while as a man he was distinguished by the honesty, faithfulness and uprightness of his character. He was elected an Associate Member on the 15th of May, 1888.

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[1] Minutes of Proceedings Inst. C.E., vol. xcv. p. 78.

LOUIS MARTINEAU, son of Mr. David Martineau, of South Road, Clapham Park, was born on the 2nd of March, 1866. He was educated at Marlborough College and at University College, London, where he greatly distinguished himself, obtaining several prizes and a Gilchrist Engineering Scholarship. From January, 1888, to December, 1890, he was a pupil in the works of Messrs. Maudslay, Sons and Field, in whose drawing office he subsequently remained until October, 1891. During that period his spare time was devoted to study, with so good a result that in 1891 he obtained a Whitworth Exhibition, being placed second on the list of that year. He then entered the works of Messrs. Laird Brothers, at Birkenhead, where he was engaged for about sixteen months on drawings for the machinery of H.M.S. "Royal Oak" and of other vessels.

In March, 1893, Mr. Martineau proceeded to Victoria, British Columbia, to take up the appointment of Manager of the Albion Ironworks in that city. In the following autumn, however, he resigned that post and entered the Dockyard and Shipbuilding Works at Newport News in Virginia. While there he received an invitation to join the staff of the contractor for the Bangkok and Korat Railway. He returned home at once, and, after spending a few weeks in England, proceeded to Siam early in October, 1894, from which time he was actively employed in bridge construction and on other works. Mr. Martineau died in Siam on the 5th of August, 1895, from inflammation of the bowels. Hard-working and full of energy, and of a kindly and sympathetic disposition, he gave promise of a successful career, which was thus prematurely cut short. He was elected an Associate Member on the 2nd of February, 1892.

LANCELOT GEORGE PRICKETT, F.C.H., born on the 15th of December, 1856, was the son of the late Mr. Thomas Prickett, J.P., of Bridlington, Deputy Lieutenant for the East Riding of Yorkshire. In 1875 he entered the Royal Indian Engineering College, Cooper's Hill, of which he was appointed a Fellow three years later. After twelve months' practical training in the works of Messrs. Westwood and Baillie at Poplar, he commenced active duty as an Assistant Engineer in the Public Works Department of the Government of India in October, 1879. He was posted to the Punjab Northern Railway as Personal Assistant to the

late Mr. Frederick L. Dibblee. In 1881 he was employed on the survey of the Sardah Canal and in the following year on the surveys for the Pilibhit and the Cawnpur-Farukhabad Railway extensions. Mr. Prickett was next engaged on the Muttra-Jumna Bridge, his work in connection therewith being specially recognised by the Government. In 1885 and 1886 he was on the Kalpi Bridge Division of the Cawnpur-Kalpi State Railway, and in the following year his services were lent to the Indian Midland Railway Company.

After some months' furlough Mr. Prickett was transferred to the Bengal-Nagpur Railway Company, his services in connection with the construction of that line being formally acknowledged by the Board of Directors. In May, 1892, he was appointed Assistant-Secretary to Government in the Railway Branch of the Public Works Department, which post he held until his death, having attained the rank of Executive Engineer in November, 1892. On the 27th of February, 1895, when on the point of taking two years' furlough to England, he was attacked by cholera, to which he succumbed in less than eight hours. Mr. Prickett was an energetic member of the Calcutta Light Horse and Honorary Secretary to the Fine Arts Club of Simla, showing considerable promise as a painter. He was elected an Associate Member on the 6th of February, 1883.

FREDERICK HENRY SMILES, son of Mr. James Smiles, of Edinburgh, was born in Edinburgh on the 14th of April, 1861. He was educated at Daniel Stewart's College, in that city, and in 1877 was indentured to the late Mr. Archibald Sutter, with whom he remained until 1883. During that time he assisted in preparing designs for, and in carrying out, the water-supply of Castle Douglas, N.B., and main roads and bridge at Newliston; and in making surveys for the lines in connection with the Forth Bridge, for the Edinburgh and South-side Suburban Railway, and for the section between Loch Lomond and Glencoe of the Glasgow and North Western Railway.

In 1883 Mr. Smiles entered the office of Mr. Alexander C. Boothby, of Kirkcaldy, and was engaged in preparing plans for the water-supply of Elie, Earlsferry, St. Monan and St. Andrews, and for the drainage of Ardross, on which works he acted as Resident Engineer for nine months. He also assisted with the parliamentary estimates, surveys and sections of the Seafield

Dock and Railway and of the Dundee Suburban Railway. In 1885 he was sent to take charge of Mr. Boothby's office in Westminster, and was there engaged for some time in the preparation of the designs for the main drainage and sewage-disposal works of Bury St. Edmunds.

In 1886, Mr. Smiles became an assistant on the engineering staff of Messrs. Punchard, McTaggart, Lowther, & Co., contractors, and for two years was engaged as a draughtsman on various South American works. In May, 1888, he proceeded to Siam for the same firm as one of a staff sent out to locate and survey the proposed Government railways from Bangkok to the Chinese frontier, and as District Engineer was in charge of sections through extremely difficult and hilly country. On the completion of that work in 1891 Mr. Smiles was appointed Chief Assistant in the Royal Survey Department of Siam, and at once started on an expedition with Mr. James McCarthy, the Superintendent of the Department, to carry out a triangulation through Northern Siam, in continuation of that brought to the frontier by the Indian Survey Department. A topographical reconnaissance was also carried on as far as Longitude 104° 30′, when the annexation by France stopped the work after about two years' continuous survey. Mr. Smiles was then engaged for a short time surveying to the north-east of Bangkok. On the 1st of April, 1895, he started on another survey, but when at Ban Chan, 11 miles from Sanka, he was seized by acute dysentery and died on the 10th of May.

As an engineer Mr. Smiles was painstaking and conscientious, and showed a cheerful devotion to his work through trying conditions of rough country and hardship. The following extract from a letter written by H.B.M. Acting Consul in Bangkok bears fitting tribute to his good qualities:—

"I cannot refrain from referring to the universal sorrow that the news of this sad event has caused in Bangkok. Mr. Smiles was, I should say, absolutely without a single enemy, and was held in great esteem by all who knew him for his many sterling qualities. It would be indeed difficult to find a man more generally liked, or one who devoted himself in so cheerful and uncomplaining a spirit to duties which were often very arduous and kept him for prolonged periods in uncivilized and insalubrious regions."

Mr. Smiles was an enthusiastic collector of botanical and natural history specimens, and not long before his death presented to the Edinburgh Museum of Science and Arts a portion of a collection of curiosities made during his residence in Siam; and to the Royal Botanical Gardens, Kew, a valuable collection of pressed flowers and plants, many of them rare and some

formerly unknown, gathered in the mountainous regions of Siam. Mr. Smiles was a Fellow of the Royal Geographical Society. He was elected an Associate Member of the Institution on the 7th of December, 1886.

JOHN PERCY STUART, second son of Mr. John Edward Stuart, of Fairview, Hampstead, was born on the 1st of July, 1861. After being educated at Christ's College, Finchley, he was articled in 1879 to the late Mr. W. F. Ashdown, of Great George Street, under whom he was engaged in surveying and preparing plans for a proposed railway between Uxbridge and Rickmansworth and for the Brentford, Isleworth and Twickenham tramways. In 1881 he was again articled, this time to Mr. William Dennis, of Westminster, for whom he had charge of the widening of the bridge connecting Devonport and Stonehouse, and of Marazion sewerage works. He was also engaged on surveying and in preparing working drawings for the Staines and West Drayton Railway, which he assisted in setting out.

In 1884, soon after the completion of his articles, Mr. Stuart proceeded to the Straits Settlements on the staff of Messrs. Hill and Rathborne, contractors, of Kwala Lumpor, Selangore. For that firm, with which he was associated for some years, he was engaged on the construction of roads, bridges and public buildings in the Straits. He was then employed on the Perak State Railway and was subsequently occupied on the Government surveys in Perak. Mr. Stuart's death was due to influenza following dysentery, from which he had suffered for several months. In spite of repeated attacks he remained at work in the jungle until within three weeks of the end, when he was carried to the hospital at Taiping, where he died on the 23rd of May, 1895. He was elected an Associate Member on the 7th of December, 1886.

ROBERT WILLIAM LYONS TOOZS, born on the 8th of February, 1856, passed from the Thomason Civil Engineering College, Roorkee, in November, 1875, into the Public Works Department of the Government of India. He was posted to the Rangoon and Irrawaddy Valley State Railway, on which he remained for eighteen months, being engaged first on survey work, then in charge of a subdivision of 25 miles, and finally in preparing plans

and estimates in the engineer's office. After acting for six months as personal assistant to the Chief Engineer of the Railway Branch in Burma, Mr. Toozs was engaged from September, 1877, on the Holkar and Neemuch State Railway, at first on works of construction and then in the traffic department, of which he officiated as superintendent for three months.

On returning from leave in September, 1879, Mr. Toozs was posted to the Indus Valley State Railway as personal assistant to the Chief Engineer. He acted in that capacity until August, 1882, when he was transferred to the Kandahar State Railway and placed in charge of a subdivision of the construction of that line, acting on several occasions during the next fifteen months as Executive Engineer in charge of 132 miles of open line. From November, 1883, to November, 1884, he took furlough on medical certificate. He was then posted to the Jhansi-Manikpur State Railway, on which he superintended the construction of a subdivision of 30 miles. In February, 1885, he was appointed to the divisional charge of the survey of the Indian Midland Railway from Gwalior to Jhansi, a length of 61 miles, of which one-third was Ghat work. On the completion of that task he was posted to the Bellary-Kistna State Railway in March, 1886, on which he remained for more than five years. During that period he had charge of the construction of various divisions, the works including heavy cuttings and embankments, large viaducts, two tunnels, and several bridges and station buildings.

From September, 1891, until March, 1893, Mr. Toozs was employed on the surveys for the Kashmir Railway, after which he was engaged for six months on the Bengal and North Western Railway. In August, 1893, he attained substantive rank as an Executive Engineer, 2nd grade, and in the following month he was posted to the Eastern Bengal State Railway, being placed in charge of the Calcutta division of that line in January, 1894. His career, however, was cut short by an unfortunate accident in the cricket-field. He was struck by a ball in the stomach, inflammation was set up and peritonitis supervened. He died at Barrackpore, after ten days' illness, on the 24th of March, 1895. Mr. Toozs was elected an Associate Member on the 4th of February, 1890.

COLONEL LEWIS CONWAY-GORDON, C.I.E., R.E. (retired), born at Southampton on the 12th of September, 1838, was the fifth son of Captain Wm. Conway-Gordon, 53rd Bengal Native Infantry, by Louisa, daughter of Brigadier-General J. Vanrenan, East India Company's Service. After being educated privately and by Messrs. Brackenbury and Wynne, Wimbledon, he entered the East India Company's Military College at Addiscombe in 1856, where he greatly distinguished himself. In his third term he obtained more marks than any fourth-term cadet and was awarded five prizes, but, owing to an obsolete regulation of the College, was not then allowed to pass out. On the expiration of his fourth term he passed out first, taking the regulation sword for exemplary conduct, the Pollock Gold Medal for distinguished proficiency, and prizes for mathematics, fortification, military surveying, civil drawing and Hindustani. At the public half-yearly examination, held on the 11th of December, 1857, the Chairman of the Court of Directors referred to him in the following terms:—

> "I must not neglect to place on record, to the high honour of Gentlemen-Cadets Conway-Gordon and Brandreth, that if the rule to which I refer had been rescinded before the midsummer examination, those gentlemen, now first and second on the list, would have won for themselves the unprecedented distinction of occupying the same positions at the head of a term as those who entered the College six months before them."

Conway-Gordon obtained a commission in the Bengal Engineers in 1857, and in 1860 he entered the service of the Public Works Department of the Government of India. For six years he remained in the Punjab, filling for part of the time the post of Assistant Principal at the Thomason Civil Engineering College, Roorkee. In 1866 he joined the Railway Branch as Assistant Consulting Engineer and Examiner of Accounts, and filled various posts as Consulting Engineer and as Examiner of Accounts until 1874. During that time he detected and exposed an extensive system of frauds on one of the lines over which he exercised control on behalf of the Indian Government, and was placed on special duty to inspect and report on the audit and accounts of the principal Guaranteed Railways.

In 1874 Captain Conway-Gordon reverted to the construction branch as Superintending Engineer on the Indus Valley (now the North Western) State Railway. His energy whilst superintending the works was untiring, and it is on record that he jumped from the bridge over the Sutlej, whilst that river was in flood, and saved the life of the Contractor's Agent, who had fallen from the

open girders and in falling had struck his head against the pier, rendering him insensible. Captain Conway-Gordon then returned to the financial branch, as Deputy Accountant-General and Under Secretary to the Government of India, and was for a time in the Accounts Branches at Lahore, Madras and Calcutta. His work in putting the Madras Irrigation Office and its accounts into proper order, was specially commended by the Government. He was always at the disposal of the Government for such work, however unpleasant and harassing, and was frequently complimented by his superiors on his readiness to start on such orders at a few hours' notice. He used to relate with some amusement an episode which occurred to him when suddenly summoned by the head of his department in Calcutta and asked if he could proceed at once to Lahore, or Mooltan, to investigate some tangled web of accounts. On his replying "Yes, in three hours," his Chief quietly said, "I must congratulate you, Major Conway-Gordon, on the health of your wife;" and, on receiving a look of enquiry, continued, "For whenever I ask anyone else to proceed suddenly on special duty, I am always met with a request for time, owing to 'the delicate health of my wife.'"

In 1881 Major Conway-Gordon was appointed Manager of the Indus Valley State Railway, then not long opened, and was specially commended for his services in connection with the arrangements for the transport of troops returning from Southern Afghanistan in that year. He then went to Simla in 1882 as Deputy Secretary to the Public Works Department, and Accountant-General. During his tenure of those offices he was several times deputed to special duties, one occasion being the enquiry by the Select Railway Committee of the House of Commons in 1884 into the best means of providing the railway accommodation required by the Indian Empire, having a due regard to finance. On returning from that duty he was appointed Manager of the Eastern Bengal State Railway and was created a Companion of the Order of the Indian Empire. In 1887 Lieutenant-Colonel Conway-Gordon was appointed Director-General of Railways, and in 1890 he was promoted to the rank of Colonel. He then took two years' furlough, his eyes having suffered from overwork. At the end of that furlough he retired, having settled at Rochester for the convenience of pursuing his favourite pastime of yachting. While at Madras he had taken up the subject of catamarans or double boats, and the "Black Deuce" was well known in those waters. He made several cruises there in a catamaran, being constantly capsized in the surf, through which, as a strong

swimmer, he easily made his way to shore. In England he pursued the subject with his accustomed energy, and if in such accomplished hands the double boat has not established an incontestable superiority, it may be assumed that the type has no advantage over the ordinary vessel. His last boat the "Heavenly Twins," the outcome of much experience and research, can do no more than hold her own.

On the 25th of June, 1895, Colonel Conway-Gordon was returning to Rochester in his yacht, the "Scotia," when she was run down in a fog off Littlehampton by a merchant steamer in the middle of the day. The fog was so thick, that though every effort was made to rescue the shipwrecked crew, only one out of the three on board was saved. Colonel Conway-Gordon was an excellent swimmer, but on this occasion was unfortunately very heavily clad, and though he was picked up just as he was sinking, it was too late to restore animation.

Of Colonel Conway-Gordon it may be said emphatically that he was a man. His long service in India had impaired neither his fine physique nor his mental energy, and while a thorough master of every detail in the offices over which he presided, there never was an official less subject to the bonds of red tape. With him, if common sense and office routine came into conflict, it was the latter which had to be reformed. This breadth of view, combined with accurate knowledge of detail, caused him to be often selected for offices which required a thorough reorganization, a work in which his energy delighted more than in the mere presiding over a machine in order. For such duties he more than once received the thanks of Government. He was one of, if not actually the first, to see the possibility of developing the Indian export trade by reducing long-distance rates; and while managing the North-Western Railway, he introduced through booking for Europe both for passenger and goods traffic. There was scarcely a branch of knowledge in which he was not well read, and though he never specially devoted himself to writing, the numerous reports, articles and pamphlets from his pen would form quite a collection. He was an excellent mechanic and always kept up a workshop; when out of the reach of his favourite pursuits of boat-building and yachting, he took up organ-building, and built two or three organs on different principles and on original lines. After his retirement his well-known abilities attracted offers to join the boards of various companies. He accepted, however, only an invitation to inspect and report on the Ruby Mines of Burma, which occupied him one winter. He was also invited to stand for Rochester in

the Liberal interest at the election of July, 1895. He interested himself in economic questions and started a co-operative barge-building association at Rochester. While in Calcutta he commanded with great success and spirit the Volunteer Lancers of that city, being highly commended by the Commander-in-Chief and the Governor-General as to the manner in which the corps turned out and performed its military exercises. His strongest point was without doubt finance, in which his ability was remarkable. Some years ago he published anonymously a treatise called "The Yellow Pamphlet," in which his financial views were stated with much force and directness. As a compliment to his success in the management of Indian Railways and with a cordial desire to assist him therein, the Great Northern Railway Company gave him complete access to its accounts and arrangements, while there was scarcely a line in this country from which he did not receive annually a "free pass."

Colonel Conway-Gordon married in 1864 Mary Grace, daughter of Mr. Joseph Cubitt—a former Vice-President of the Institution—who, with two sons and a daughter, survives him. He was elected an Associate on the 4th of December, 1866.

JOHN HENRY GREENER was born at Etherly, Durham, in 1829. At an early age he came to London and obtained an engagement on the Blackwall Railway, where he first made practical acquaintance with the electric telegraph. As an assistant to Sir William Fothergill Cooke, he was one of the earliest telegraph operators in this country. In 1846 he entered the service of the Electric Telegraph Company (afterwards the Electric and International Telegraph Company), of which the late Mr. Edwin Clark was appointed Engineer-in-Chief in 1850.[1] Mr. Greener was directed by the Company in 1853 to superintend the construction of the telegraph on the Norwegian Trunk Railway, the first line of telegraph in that country, and two years later he was sent to Denmark to perform similar duties on the Government railways of that kingdom. On the completion of that work he was ordered to Ireland, to report on the state of the telegraph lines between Dublin and Galway, in view of the establishment of direct communication with the Atlantic cable,

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[1] Minutes of Proceedings Inst. C.E., vol. cxx. p. 349.

and on his return home was appointed outdoor assistant to Mr. Latimer Clark, who had succeeded to the post of Chief Engineer to the Company.

On the temporary failure of the Red Sea cable in 1860, it was considered advisable that England should have a second means of telegraphic communication with India, and Mr. Greener was selected by the Secretary of State for India to examine and report upon the condition of the Turkish telegraph lines from Constantinople to the Persian Gulf, through Asia Minor and Turkish Arabia. In 1862 he returned home and reported to the India Office as to the possibility of the extension of the Turkish lines through Mesopotamia to Fao at the head of the Persian Gulf, and in the same year he was sent to Bombay to accompany, as Telegraph Engineer, the expedition dispatched to take soundings and to select suitable stations as landing-places for the proposed cable from Karachi to Fao. Mr. Greener constructed the line from Baghdad to Fao, whence a cable to Karachi was successfully laid, and telegraphic communication between England and India by this new route was completed in 1864.

On returning to this country in 1865 Mr. Greener was appointed Inspecting Engineer for Telegraph Stores to the India Office, and subsequently he also performed similar duties for the Crown Agents for the Colonies and for the Agent-General for the Cape of Good Hope. He severed his connection with the India Office a few years since, but retained his post at the Colonial Office until his death, which took place at Herne Hill on the 7th of April, 1895. Mr. Greener was elected an Associate on the 4th of February, 1868.

*** The following deaths have also been made known since the 3rd of July, 1895:—

Members.

DENNY, PETER, LL.D.; *born* 31 October, 1821; *died* 22 August, 1895. (*Malarial fever.*)

MACADAM, PHILIP HENRY; *died* 6 July, 1895, *aged* 64.

Associate Member.

BINNS, WILLIAM; *born* 4 March, 1815; *died* 31 March, 1895. (*Pneumonia.*)

Information as to the professional career and personal characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., *August*, 1895.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Methods of insuring greater Accuracy in Telescopic Measurements.

By L. S. SMITH.

(Engineering News, New York, 1895, p. 364.)

Thinking that the unsteadiness or "boiling" of the air exercised a governing influence on the accuracy of stadia surveys, the Author made an experimental study of the subject during the course of the fieldwork of the Boundary Survey between the United States and Mexico in 1892–3, a study that he continued in the summer and autumn of 1894 in Wisconsin. He found, however, that his assumption was not correct, and that the cause was what he calls differential refraction, a term used to express the difference in the amounts that the two lines of sight, upper and lower, are refracted by the air. This unequal refraction may be due to the increased temperature in the course of a sunny day causing a rarefaction which, within a short distance of the ground, makes the density of the air increase upwards, and rays of light traversing this stratum are bent upwards. The depth of the abnormal stratum varies at different hours and seasons, but that portion of it in which the change of density is most rapid is never more than 4 feet deep.

The length of sight giving the maximum accuracy of measurement was ascertained from the results of 422 test-sights, aggregating 85 miles, made during July and August on a base line, accurately measured by a standardised steel tape. Corrections for temperature and inclination were made, so that the probable error was less than 1 in 25,000. The work consisted of twenty to thirty readings on nineteen stations, 100 feet apart, varying from 200 feet to 2,000 feet from the theodolite. Of the 217 readings taken during the good-seeing period (from 7 to 9 A.M. and 2.30 to 7 P.M.) 66 per cent. of the errors were positive, 30 per cent. negative, and 4 per cent. nil; while, for the midday work (9 A.M. to 2.30 P.M.) the proportions of negative and positive errors were reversed. In the first division of work, however, the positive errors were larger than the negative, and in the second case the negative errors were many times larger than the positive. The probable error of a single reading during the morning and evening hours was about 1 in 1,000, while during midday the error was 1 in 430 for sights less than 1,000 feet in length, and 1 in 200 for sights 1,100 to

2,000 feet in length. The errors are plotted by the Author as curves, with the length of the sight in feet as abscissas and the probable errors of such lengths as ordinates. The practical deductions to be drawn from the results are, that accurate work should not be attempted in hours not represented by the staff-interval determination, and that in the hours from 9.30 A.M. to 2.30 P.M. sights should not be taken if they require the lower line of sight to pass nearer than 4 feet from the ground. If long readings cannot be avoided they should be taken by half intervals at the upper portions of the staff.

Many errors may be explained by the hour at which the interval used in the graduation of the staff was determined, and hardly two engineers agree as to the proper time. The Author's researches clearly show that the interval should be determined not at any particular hour, but during all field hours, so as to approximate, as closely as time allows, to the average conditions of field work. It would be most convenient to avoid incorporating the interval in the design of the staff, as is at present so generally done in the United States, and to use instead staves divided into standard units of length. This involves the computation of true distances by means of an interval factor, but with tables such computations may be made with great rapidity. The principal advantages of the interval factor method over the older one are as follow: (1) Subsequent tests of interval can be made without the expense of repainting and regraduating the staff; (2) staves can be interchanged among instruments; (3) staves can be used by different observers; (4) ordinary levelling staves may be used.

B. H. B.

The Resistance of Materials under Impact.

By MANSFIELD MERRIMAN.

(Proceedings of the American Association for the Advancement of Science, August, 1894, p. 174.)

Resilience has been defined as the action which resists impulse; strength, as the action which resists pressure. The resilience of a body is proportional to its strength and extension jointly, and is measured by the height through which a given weight must fall to cause rupture. It is the capacity of a body to resist applied work.

It is necessary to distinguish between elastic resilience and non-elastic resilience. Hence there are two divisions of the subject of impact: first, that of elastic resilience when the molecular forces do not surpass the elastic limit of the material; and second, that of ultimate resilience when the elastic limit is exceeded and rupture finally occurs.

The elastic resilience of bars or rods subject to the longitudinal

or vertical impact of a moving weight, has been determined by experiment. In the case of a horizontal bar subject to longitudinal impact, the maximum elongation is a mean proportional between twice the height of fall and the extension due to the same weight when applied gradually; while, for a vertical bar upon the end of which a falling weight impinges, it is the sum of the static extension and the hypothenuse of a right-angled triangle whose sides are this static extension and the dynamic extension stated for the horizontal bar. Under the sudden application of a load which is the particular case of impact when the height of fall is zero, the maximum elongation, and hence the maximum internal stress, is twice as great as that caused by the same load when applied gradually.

These conclusions are only true when the conditions are observed under which they were deduced; namely, that the elastic limit is not exceeded by the maximum internal stress. While the elastic limit for some materials is as high as one-half the ultimate strength, the elongation up to the elastic limit is small compared with the ultimate elongation, and hence the elastic resilience may be very small, less perhaps than one part in a thousand compared with the total ultimate resilience.

The investigation of ultimate resilience is necessarily experimental, since beyond the elastic limit no theoretical relation between stress and deformation is known. Experiments on cast-iron beams under lateral impact from a pendulum showed that the deflections were proportional to the velocities of impact, and that the same work was required to break the beam whether struck at the middle or at the quarter point, and that the weight of the beam increased its ultimate resilience. By transverse impact, by oft-repeated blows of a pendulum, and also by pressure applied by a revolving cam, the laws of fatigue were discovered, and it was found that the same amount of work was required to rupture a rectangular beam, whether struck on its narrow or broad side, showing that the resilience of beams of the same kind is proportional to their volume, and that inertia is an important factor in increasing resilience.

Weights suddenly applied without impact give deflections nearly double the static deflections, and a load moving over a beam may cause a deflection of more than double the static deflection. Static tensile tests will give an approximate measure of the ultimate resilience per cubic unit of the material, as the internal work which resists rupture is proportional to the area of a diagram formed by laying off the unit stresses as ordinates, and the corresponding elongations as abscissas. The law that the stress produced by a gradual load is one-half that produced by a load suddenly applied is only true when the elastic limit is not exceeded. For ultimate resilience the ratio of gradual to sudden load producing the same stress is always greater than one-half, and approaches nearer to unity the more ductile the material.

The rise of the elastic limit after the relief of a stress which

surpasses it, and the consequent stiffening of the material under several such applications of stress, are observed in cases of repeated impact, but our knowledge as to what occurs under these conditions is of the most uncertain kind. Most of the stresses are no doubt injurious, causing fatigue, but a few may be beneficial, improving the quality of the material. The discovery that the raising of the tensile elastic limit is accompanied by a lowering of the compressive elastic limit is important in this connection.

Experiments on the resilience of materials, under repeated stresses applied with little impact, show that when the elastic limit is not exceeded the material is uninjured, but that repeated stresses beyond this limit cause injury in proportion to the range between the maximum and minimum limits, and that the greater the range the less the number of repetitions required to produce rupture. The ultimate elongation under repeated stress is about one-third greater than for static stresses, probably on account of the beneficial influence of some of them.

A low fall combined with a heavy ram is best adapted for impact tests, as, if the ram be light, local damage in the body struck will be the result rather than development of its resilience. The surface of contact should be sufficiently large, that the compression of the ram may not exceed the elastic limit, and thus loss of work in heat may be avoided. In elastic resilience the applied work is not transformed into heat, in resilience accompanied by permanent deformation it is; and hence the tests should be so conducted that the specimen and not the ram may be heated. The rebound of the ram should be subtracted from the total fall to obtain an exact measure of the work actually performed by it upon the body which is tested. The mean value of the pressure caused by the impact of the ram, multiplied by the distance through which it acts, is equal to the total work done in the fall; but the variations of pressure, or its maximum intensity, cannot be easily computed except in some cases when the elastic limit is not exceeded.

In conclusion, the Author considers that great importance should be attached to impact tests, and quotes in support of this view the opinion of Sir Benjamin Baker, that for judging the ductility of metal, when the method of direct tension was applicable in one case in a hundred, in the other ninety-nine the simple cold bending of a bar was generally used and was just as sound a test.

The Author hopes that in a few years methods may be devised by which full numerical information regarding all the physical qualities of materials can be obtained from simple tests of their elastic and ultimate resilience.

S. W. B.

Experiments on the Elasticity of Concrete. By C. Bach.

(Zeitschrift des Vereines deutscher Ingenieure, 1895, p. 489.)

In tabulating and stating the results of his investigations on the strength of concrete, the Author, who has during the past few years carried out several exhaustive series of experiments on the strength of various materials, calls attention to the fact that in most of the hitherto-recorded experiments on concrete the test-blocks have been of such small dimensions that it must be evident that the component materials, if mixed on a practical scale (*i.e.*, such as they would be in the actual execution of any work), could not possibly afford results of any uniform or comparative accuracy; while if specially selected and packed to form a small block in a manner not applicable in actual construction the result cannot afford any reliable information as to the practical strength of the material. A further point in which it appears needful to supplement previous records is in clearly stating the variation between temporary and permanent set — in other words, the elasticity of the material.

In order to secure tests upon a practical and reliable basis, the Author had thirty-six blocks prepared, each 9·84 inches in diameter and of an average length of 39·37 inches. The following were the six mixtures experimented upon:—

I.	1 of Portland cement,	2½ sand, 5 gravel.
II.	1 " "	2½ sand, 5 limestone shingle.
III.	1 " "	7½ sandy gravel.
IV.	1 " "	3 sand, 6 gravel.
V.	1 " "	3 sand, 6 limestone shingle.
VI.	1 " "	9 sandy gravel.

Six test-blocks were made in each of these mixtures: three being with Portland cement from Blaubeuren, and three with cement from Lauffen-on-Neckar. On passing the cement through a sieve of 5,600 meshes to the square inch, the residue from the former was 1·9 per cent., and from the latter 3·3 per cent. The normal tests at twenty-eight days after mixing (one day in air and twenty-seven in water) gave the following respective breaking weights:—

Blaubeuren cement concrete . .	362·6 lbs. per square inch.
Lauffen " " . .	301·5 " " "

The measurements were taken on a length of 29·5 inches; and the following was the arrangement adopted with each block. The two ends of the block having been planed to absolutely parallel faces, two metal rings were securely clamped round the block at a distance of 29·5 inches centre to centre. The lower ring carried a small block dished on the upper surface to form a bearing for a vertical steel-bar, the upper end of which just came in contact with the short-arm of a lever mounted on a plate

carried on the upper ring, when the said lever was in its normal position of rest at right angles with the axis of the test-block. The long-arm of this lever was fitted with a rack, giving motion to a pinion on the spindle of which was mounted a needle-pointer registering on the face of a large-graded sector. In the normal position as above described the pointer indicated zero. The compression of the block, bringing the rings closer together, caused the freely-moving bar to push the short-arm of the lever upwards, and the pointer (through the rack-and-pinion motion) to rise on the sector. The instrument was so proportioned that for 1 millimetre compression on the test-block the pointer would traverse 300 millimetres on the sector. The scale being graduated to $\frac{1}{10}$ millimetre (0·0039 inch) divisions, the readings were equivalent to 0·000013 inch on the block—*i.e.* to $\frac{1}{2,250,000}$ of the test-length under measurement. The measurements were taken in duplicate, on each side of the block, so that any inequality was distinctly recorded. Each successive load was applied and removed at 1½ minute intervals until the permanent and temporary set remained constant under three consecutive loadings; in other words, until the definite limit of elasticity was reached for each load. The next increase of load was then made, and so on. The subjoined Table, recording the successive variations in one block under repeated applications of the same load, and under increasing loads, illustrates the method pursued throughout the experiments.

Load.		Number of Times Loading and Unloading repeated until no further Variation.	Percentage of Contraction.		
Total (Tons).	Lbs. per Square Inch		Temporary.	Permanent.	Total.
4	112·3	4 [1]	Varying from 0·188	0·027	0·215
			to 0·193	0·028	0·221
8	224·7	5	„ from 0·412	0·052	0·464
			to 0·425	0·058	0·483
12	337·0	5	„ from 0·662	0·083	0·745
			to 0·687	0·092	0·779
16	449·4	6	„ from 0·920	0·132	1·052
			to 0·967	0·152	1·119
20	561·7	8	„ from 1·207	0·190	1·397
			to 1·272	0·238	1·510

The maximum figures for each load represent therefore the ultimate elastic strength of the material.

The following Table summarises the results of the series of experiments with the Blaubeuren cement concrete blocks. [The second column refers to the number of the mixture: the letters *a*, *b*, *c* indicating the successive three blocks of each mixture.]

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[1] *I.e.* four repetitions of loading and unloading, with increasing percentage of contraction, then three repetitions without any variation in effect; and similarly with the following series.

PERCENTAGE CONTRACTION OF BLAUBEUREN CEMENT CONCRETE UNDER VARYING LOADS.

Series of Experiments.	No. of Mixture and of Sample.	Nature of Set.	Contraction in Percentage of Test Length. Test Loads. 4 Tons.	8 Tons.	12 Tons.	16 Tons.	20 Tons.	Coefficient of Contraction.	Ultimate Tenacity.
									Lbs. per Sq. Inch.
1	Ic	Elastic or Temporary	0·193	0·425	0·687	0·967	1·272	$\frac{1}{306,000}$	1,369·4
		Permanent	0·028	0·058	0·092	0·152	0·238		
		Total . .	0·221	0·483	0·779	1·119	1·510		
2	IIa	Temporary	0·160	0·415	0·674	0·940	1·227	$\frac{1}{329,000}$	1,787·4
		Permanent	0·023	0·043	0·063	0·096	0·133		
		Total . .	0·183	0·458	0·737	1·036	1·360		
3	IIb	Temporary	0·153	0·340	0·685	0·943	1·233	$\frac{1}{386,000}$	1,983·7
		Permanent	0·056	0·092	0·127	0·165	0·217		
		Total . .	0·209	0·432	0·812	1·108	1·450		
4	IIc	Temporary	0·160	0·400	0·630	0·863	1·152	$\frac{1}{333,000}$	1,804·5
		Permanent	0·023	0·056	0·092	0·116	0·147		
		Total . .	0·183	0·456	0·722	0·979	1·299		
5	IIIa	Temporary	0·175	0·412	0·672	0·932	1·207	$\frac{1}{343,000}$	1,865·7
		Permanent	0·030	0·067	0·106	0·150	0·195		
		Total . .	0·205	0·479	0·778	1·082	1·402		
6	IIIb	Temporary	0·172	0·378	0·593	0·832	1·073	$\frac{1}{350,000}$	2,009·3
		Permanent	0·018	0·037	0·060	0·088	0·123		
		Total . .	0·190	0·415	0·653	0·920	1·196		
7	IIIc[1]	Temporary	0·190	0·410	0·658	0·902	1·157	$\frac{1}{316,000}$	2,093·2
		Permanent	0·025	0·058	0·075	0·107	0·140		
		Total . .	0·215	0·468	0·733	1·009	1·297		
8	IVa	Temporary	0·188	0·410	0·650	0·903	1·155	$\frac{1}{315,000}$	1,636·7
		Permanent	0·013	0·073	0·103	0·135	0·168		
		Total . .	0·201	0·483	0·753	1·038	1·323		

[1] See following Table.

PERCENTAGE CONTRACTION OF BLAUBEUREN CEMENT CONCRETE UNDER VARYING LOADS—*continued.*

Series of Experiments.	No. of Mixture and of Sample.	Nature of Set.	Contraction in Percentage of Test Length. Test Loads. 4 Tons.	8 Tons.	12 Tons.	16 Tons.	20 Tons.	Coefficient of Contraction.	Ultimate Tenacity.
									Lbs. per Sq. Inch.
9	IV*b*	Temporary	0·200	0·440	0·705	0·970	1·238	$\frac{1}{296,000}$	1,565·6
		Permanent	0·037	0·068	0·088	0·135	0·183		
		Total . .	0·237	0·508	0·793	1·105	1·421		
10	IV*c*	Temporary	0·203	0·452	0·703	0·970	1·240	$\frac{1}{295,000}$	1,702·1
		Permanent	0·032	0·053	0·080	0·103	0·128		
		Total . .	0·235	0·505	0·783	1·073	1·368		
11	V*a*	Temporary	0·173	0·388	0·648	0·927	1·218	$\frac{1}{346,000}$	1,686·5
		Permanent	0·010	0·037	0·067	0·108	0·145		
		Total . .	0·183	0·425	0·715	1·035	1·363		
12	V*b*	Temporary	0·183	0·412	0·652	0·942	1·235	$\frac{1}{327,000}$	1,722·0
		Permanent	0·007	0·042	0·070	0·108	0·150		
		Total . .	0·190	0·454	0·722	1·050	1·385		
13	V*c*	Temporary	0·188	0·427	0·688	0·972	1·265	$\frac{1}{315,000}$	1,639·6
		Permanent	0·027	0·045	0·085	0·120	0·172		
		Total . .	0·215	0·472	0·773	1·092	1·437		
14	VI*a*	Temporary	0·197	0·418	0·652	0·903	1·175	$\frac{1}{301,000}$	1,511·6
		Permanent	0·005	0·030	0·057	0·093	0·147		
		Total . .	0·202	0·448	0·709	0·996	1·322		
15	VI*b*	Temporary	0·188	0·395	0·623	0·867	1·127	$\frac{1}{319,000}$	1,666·6
		Permanent	0·030	0·060	0·077	0·100	0·113		
		Total . .	0·218	0·455	0·700	0·967	1·240		
16	VI*c*	Temporary	0·165	0·363	0·573	0·802	1·032	$\frac{1}{364,000}$	1,962·4
		Permanent	0·005	0·020	0·045	0·068	0·088		
		Total . .	0·170	0·383	0·618	0·870	1·120		

As an illustration of the further series of tests up to the

breaking point, the series of experiments with higher loads on block IIIc (see preceding Table) may be quoted:—

Load.		Percentage of Contraction.		
Tons (Total).	Lbs. per Square Inch.	Temporary.	Permanent.	Total.
20	561·7	1·157	0·140	1·297
24	674·0	1·355	0·178	1·533
28	786·4	1·665	0·223	1·888
32	898·8	1·932	0·300	2·232
36	1,011·1	2·205	0·385	2·590
40	1,123·4	2·503	0·470	2·973
44	1,235·7	2·810	0·530	3·340
48	1,348·0	3·142	0·675	3·817
52	1,460·3	3·493	0·823	4·316
56	1,572·8	3·898	1·022	4·920
60	1,685·1	4·297	1·237	5·534
64	1,797·6	4·857	1·568	6·425
68	1,909·7	5·580	2·137	7·717
74	2,093·2		Breaking point	

In the preceding series of experiments with Blaubeuren cement, the maximum and minimum results as shown in the Table are:—

Highest ultimate tenacity (2,093·2 lbs. per square inch) mixture No. III.
Lowest „ „ (1,369·4 „ „ „) „ No. I.
Least permanent set (0·088 per cent.) . . . . . . „ No. VI.
Greatest „ „ (0·238 „ „) . . . . . . „ No. I.

The series of blocks formed with cement from Lauffen-on-Neckar was tested in a precisely similar manner. The general results are inferior to the first series, and may be thus briefly summarised:—

Highest ultimate tenacity, 1,616·8 lbs. per square inch.
General range of ultimate tenacity, from 881·6 to 1,279·8 lbs. per sq. in.
Least permanent set (0·210 per cent.) . . . . . mixture No. II.
Greatest „ „ (0·555 „ „) . . . . . . „ No. VI.

From the preceding summaries the important influence of the binding material is clearly evident upon both the temporary and permanent character of the concrete mass.

P. W. B.

Report of the Proceedings of the Commission appointed by the Brussels Section to determine rules for the Classification and Test of Hydraulic Materials.

(Annales de l'Association des Ingénieurs sortis des Écoles spéciales de Gand, 1894–95, p. 165.)

This Commission included Messrs. Camerman, Casse, De Schryver, De Sébille, Flamache and Pineur.

In the following classification, simplicity, some security for the makers, and a very clear distinction between the classes, were aimed at. (i) Fat and poor limes, including all materials obtained by burning limestone which are completely slaked by the addition of water, and have an index of hydraulicity between 0 and 0·10. (This index is the proportion of silica and alumina to lime.) (ii) Hydraulic limes; these are obtained by burning clayey limestones, are partially or completely slaked by the addition of water, and have an index of hydraulicity greater than 0·10. (iii) Portland cements, obtained by burning clayey limes, or a mixture of clay and lime, the burning being carried up to the fusing point. These cements have to be mechanically ground, and their index of hydraulicity is less than 0·60. (iv) Roman cements, similar to Portland cements, but with an index of hydraulicity greater than 0·60. (v) Hydraulic gangues, materials which do not in themselves possess the property of setting by the addition of water, but which form hydraulic cements when mixed with lime. Such are trass, puzzolana, basic slags, &c. (vi) Puzzolana cements, a mixture of lime and gangue in powder, distinguished by the name of the gangue used. (vii) Mixed cements formed by the mixture of any one of the above cements with other material to suit special requirements, and distinguished by the name of the added material.

Under the second head, tests of time of testing and of strength are recommended for limes, quick-setting and puzzolana cements, tests of the latter being the best way of testing the value of the gangues of which they are composed. Care is necessary in the making of the test-bricks, and tests of weight per bushel are not recommended, as the weight is affected by the fineness of grinding. Tests of mortar are preferred to those of neat cement, and the stability of the materials should be tested by exposure to boiling water or steam. For testing hydraulic gangues, great care must be taken to thoroughly slake the lime used, and a method of doing so is described, as well as of obtaining samples of the lime and gangue in powder. For tests of puzzolana cements, two parts by weight of gangue, one part of fat slaked lime, and one of water are specified, three parts of sand being added for tests of mortar, while for other mortars the test samples should be formed of one part of cement or lime to three parts of sand. The method is described of obtaining a "normal consistency" of the sample bricks, and of the test for time of setting, both in air and under oil. The sand

used should be either washed sand, or powdered quartz, carefully sifted so as to pass through a sieve of 413 meshes to the square inch, and be retained on one of 929 meshes. Rules are given for the making of test-bricks, both for compressive and tensile tests, for the care of them till they are tested, and for determining the fineness of grinding. The method of obtaining the specific gravity by a Schumann apparatus is also described. The report concludes with a Table giving the requirements which should be satisfied by the various hydraulic materials, including tests for fineness, tensile and compressive tests of mortar after seven and twenty-eight days, and time before the cement commences to set, and sets completely in air and in petroleum. Pure trass should not lose more than 7 per cent. in weight when exposed to a heat of 100° C., and all materials should be unchanged by exposure to steam or boiling water. The minimum specific density of artificial and natural Portland cement is given as 3·10 and 3·05 respectively.

R. B. M.

The Use of Steel in Large Buildings. By CARYDON T. PURDY.

(Journal of the Association of Engineering Societies, Philadelphia, March, 1895, p. 182.)

The Author describes the new American building as a complete steel framework enclosed by concrete and masonry. The horizontal bracing is formed by the floors and the vertical bracing between the riveted steel columns by knee bracing, lattice girder, diagonal bar, or portal bracing. Illustrations are given of these bracings. For the prevention of corrosion it is of importance to use impermeable substances and mortar, not made of lime but of Portland cement, to cover the metal in dry weather, to keep water-pipes at a distance and not to expose the bottom flanges of girders. In order to make the buildings fireproof, marble, limestone and lime mortar should be avoided, and columns should be enclosed by round tiles, leaving a hollow space next to the metal.

M. A. E.

Wind-Bracing in High Buildings. By GUY B. WAITE.

(Transactions of the American Society of Civil Engineers, March, 1895, p. 190.)

The Author, an examiner of building construction in the Department of Buildings of New York City, investigates the resistance to wind-pressure in modern iron framework buildings, many of which reach a height of from 120 to 175 feet with a depth of 23 to 25 feet and some to a height of 250 feet, and obtains generally unsatisfactory results. He takes a wind-pressure of only 30 lbs. per square foot or of a velocity of 87 miles per hour

($P = 0 \cdot 004\ v^2$), and endeavours to include all elements of strength which might be claimed by designers, viz., the bending resistance of front and rear walls with their columns, the stability of the end walls to which the wind-pressure is transmitted by the floors, the strength of the partitions and inner columns, and the continuity of the columns if knee-braces are introduced between them and the floor girders. For example, in a seventeen-storey building 194 feet high, 32 feet by 100 feet in plan and rising 144 feet above the adjacent building, which he assumes as completely firm, he finds compressive stresses of about 9 tons per square inch in the cast-iron columns from the dead load alone, which he considers excessive. The Author disapproves of the use of cast-iron columns in buildings of this class, and recommends a careful execution of the details of construction.

M. A. E.

Road-making in the Hanoverian Plain, and the system of Small Stone Pitching.

(Zeitschrift des Architekten und Ingenieur Vereins, Hannover, 1895, p. 19.)

The province of Hanover, as regards its roads, may be divided into three distinct districts, viz., the mountainous portions, including the Hartz, where the most durable stone, such as granite, basalt, &c., is plentiful; the lower lying highland, as in the neighbourhood of Hildesheim, Deester, Osnabrück, &c., where limestone is abundant; and lastly, in the plain and along the coast, where there is practically no quarry stone, and erratic boulders (*findlinge*) only are to be found. Until the beginning of this century, in the Hanoverian plain, metalled roads were unknown, and it was Napoleon I. who showed the possibility of utilising erratic boulders for the purpose, by the construction of the Hamburg, Bremen, and Heer highway, which still exists practically in its original form. The general course of this road is straight, and its width is about 49 feet 3 inches (15 metres). In the middle is a paved way of 14 feet 9 inches (4·5 metres) for heavy traffic; next to that is a metalled road 11 feet 6 inches (3·5 metres) in breadth for light traffic, and a like width of unmetalled road for agricultural traffic in summer. Next to the metalled width is a footway of 4 feet broad, and next the summer track a benching of 5 feet 3 inches in breadth. This was the commencing of a network of stone-laid roads which, by the year 1890, had extended in the province of Hanover to 3,107 miles. For the low-land roadways, in addition to the broken boulders which are becoming more and more difficult to procure, a considerable length is metalled with blast-furnace slag, the most valuable of which is that produced at the Ilseder Iron Works, near Peine.

In 1890 there were 335 miles (541 kilometres) of slag-metalled roads in the province. For the roads near the coast Oldenburg

clinkers are much used, as also are Ems clinkers, of which the price is less than the former. In 1890 there were 450 miles of clinker-metalled road in the province.

The increase in cost of transport of material in the lowlands, with the increase in distance from the quarries, blast-furnaces, brickyards, &c., as the case may be, has led to a careful consideration of the subject with a view to diminishing the cost of maintenance to a minimum, and one of the principal objects of the Paper is to describe a method (Gravenhorst's of Stade) of small stone-pitching. This system is most advantageous where a metalled road has become worn out, and it is used as a means of repair in place of a new surface of broken stone laid at random. The old surface is first carefully levelled up, additional metalling being used if necessary. The edge-stones are set so as to stand about 2⅓ inches (6 centimetres) above the metalled surface and serving as a border for the pitching. The surface of metalling is well rolled, as it is most essential that it should be thoroughly consolidated and even in surface. A layer of about ½ inch of sand, or fine gravel, is then laid, and in this the small pitching-stones are laid as in a mosaic, resembling the mosaic work adopted for footways, but coarser. The stone for pitching is dressed, approximately, to the form of cubes with a side of 2½ inches to 3 inches; in practice it is found that exactness of form is not so essential, but that special attention must be given to having the adjacent stones identical in thickness. The freshly-set pitching is thoroughly watered and rammed. With 1·308 cubic yard (1 cubic metre) of these pitching-stones an area of 12 square yards to 13 square yards of pitching can be laid. The total cost of course varies with the locality; in the vicinity of Stade it amounts to from 10 per cent. to 20 per cent. more than a new topping of random-laid broken stone (macadam).

Where entirely new roads are laid on this system, stress is laid upon the absolute necessity for having a thoroughly consolidated foundation, as any subsidence in the substratum immediately affects the surface. The earliest road laid in this way was in 1885, and is now in good order. For the pitching quarry-stone is used as well as broken boulders; the comparative prices must depend upon the locality, but quarry-stone has the advantage of being the easier dressed.

The various sources from which stone, slag and clinker are procured and a description of them are given, as also the length of roadway laid and the localities. The total at the beginning of 1894 was 52 miles, and it was proposed to lay a further 15½ miles in the neighbourhood of Gottingen and Hanover in that year. As compared with the ordinary pitching with large blocks for heavy traffic roads, the prices are about £725 per mile as against from £2,012 to £2,415 per mile for the latter, and a comparison of the items of the light and heavy pitching is given, the prices being 3*s*. 1*d*. and 5*s*. 10*d*. per square yard respectively.

D. G.

The King Charles Bridge between Stuttgart and Cannstatt.

By Professor v. LEIBBRAND.

(Zeitschrift des Vereines deutscher Ingenieure, 1895, p 153.)

The twin towns of Stuttgart and Cannstatt, on opposite sides of the River Neckar, were, until recently, connected by only one bridge; but their great development in recent years rendered the construction of a second means of communication an absolute necessity.

The site being decided upon, after trial-borings and careful consideration of alternative plans, the work was put in hand, the design being an arched masonry bridge. The borings showed sand and gravel beds, with a good bottom for the central piers at about 30 feet below low water, the ground at the abutments being somewhat better. In the early stages of sinking the piers, however, it became evident that in spite of the apparent sufficiency of the trial-holes, and of the driving of trial-piles, the substratum was too soft for the proposed structure, so that the execution of the masonry bridge, in which the pressure on foundations would be about 4·6 tons per square foot, had to be entirely stopped, and the plans revised throughout. In the end, an iron superstructure was decided upon, the piers and abutments retaining substantially their original dimensions, and the foundation-load being thus reduced to 2·74 tons per square foot.

The iron caissons for the river piers were 87 feet 7 inches long, 22 feet 4 inches wide and 8 feet 3 inches deep; sectional area 1,841 square feet, and weight 50 tons. The work in the foundations was carried out under compressed air and by electric light. The average rate of sinking was 8 inches to 10 inches per diem, the total work on each pier averaging about forty-five days. The facework of the pier is of sandstone, with granite dressings and starlings, and concrete core. The superstructure is formed of six parabolic girders 4 feet 1 inch apart, centre to centre, 2 feet 6 inches deep at crown, and 3 feet deep at springing, with vertical members and diagonal bracing to carry the cross-girders and road platform. The three spans are respectively 149 feet 3 inches, 157 feet 6 inches and 165 feet 8 inches. All the work is of soft steel, and was built up on centering. The roadway is 36 feet 1 inch wide, and is formed of 6-inch creosoted wood-blocks on concrete; the footways are paved in asphalt. The maximum live load is taken at 82 lbs. per square foot for the roadway and 115 lbs. per square foot for the footways. The bridge is treated rather elaborately in its architectural features, the design including four pylones at the abutments, each 56 feet high. The steelwork weighs 1,322 tons and cost £21,000, the total cost of the bridge and approaches being £66,900.

P. W. B.

Graphic Diagrams for the calculation of Stresses in Metal Bridges with Braced Girders. By L. ROGER.

(Le Génie Civil, July 20, 1895, p. 187.)

The Author's object in this Paper is to construct a diagram whereby the maximum bending moment at any point of a bridge, due to the passage of a standard train (*i.e.* the regulation train-load fixed by the French Government in 1891), can be easily determined. The diagram can be modified so as to be applicable to any distribution of rolling load whatever.

With a pair of rectangular axes, the Author takes the abscissas to represent the spans, and the ordinates the distances from one abutment. Thus any ordinate represents a series of points on a bridge whose span is the distance of that ordinate from the origin of co-ordinates. This ordinate, therefore, cannot be longer than the span of the bridge, that is, greater than the abscissa, and the diagram is limited to a triangular space, bounded by the axis of x and a line inclined to it at an angle of 45°, and passing through the origin.

The Author then proceeds to divide up this space by means of lines, the spaces between which are numbered to correspond with the several axles of the train under consideration. Taking say the spaces marked 8 and 9, it will be found that at any point of the line dividing them the bending moment due to the train when axle No. 8 is at that point is equal to the bending moment of the train when axle No. 9 is at that point; while for all points within the area No. 8 the former bending moment is greater than the latter, and *vice versâ* for all points within the area No. 9. The Author explains how these curves are to be obtained. When the diagram is complete, in order to ascertain which axle of the train must be at any given point of a bridge of any given span, in order to produce the greatest bending moment at that point, it is only necessary to ascertain the number of the space on the diagram within which is situated the point corresponding to the required point on the bridge in question. For small spans these lines are very irregular, but they gradually straighten out as the spans increase.

To further facilitate calculation the Author gives a simple diagram whereby, for any given position of the train on a bridge, the bending moment at any point may be easily determined, as well as the maximum shearing stresses due to that particular train.

The Paper is accompanied by a double-page plate of the diagrams, as well as by fourteen illustrations in the body of the Paper. Two of these, however, are little more than reproductions of the larger diagrams.

R. B. M.

The Bridge over the Tennessee River at Johnsonville, Tennessee.

By HUNTER MACDONALD.

(Transactions of the American Society of Civil Engineers, March, 1895, p. 171.)

The bridge was built in 1866 by the Nashville and North Western Railroad Company for a single line. There are seven fixed spans of about 165 feet and two swing-spans of about 116 feet each. The masonry piers are about 50 feet above low-water and the high-water of 1882 was level with their top. The foundations consisted of timber cribs laid on the hard blue clay, and the masonry was built upon them without the need of cofferdams; loads of rock and slag were thrown around the cribs. Three piers, including the pivot pier, began to settle in 1871 in consequence of scouring accompanied by the formation of islands in the river, and in 1890 two spans were blown away by a tornado. These damages having been attended to, a new bridge was proposed above the old one, but on account of the unfavourable position of the Company, not executed. Instead of that, a swing-bridge of two spans, about 200 feet each, was built in place of the old swing-bridge and one adjoining span. The piers, having a timber caisson foundation filled with concrete, were carried down to the rock, that is about 30 feet below the old foundations, but five of the old piers having shown no settlement, were left intact. The whole platform was raised 4 feet 6 inches. The work was finished on December 20th, 1893.

M. A. E.

Notes on Hydraulic Riveting at the Erection of the Bridge over the Oignon. By — GEOFFROY.

(Annales des Ponts et Chaussées, April, 1895, p. 349.)

The Author, who in a former paper[1] described some experimental hydraulic riveting at the erection of the Borne Bridge, here gives details of the hydraulic riveters used in the erection of the railway bridge over the Oignon. This was a single-line bridge of 133·5 feet span. The main girders were 137·8 feet long over all, 13·45 feet deep, 16·4 feet apart centre to centre, connected on the lower boom by cross-girders 2·7 feet deep, with rail-girders 1·64 foot deep, and corrugated floor plates riveted both to the cross- and rail-girders. The girders were divided into twelve bays on the vertical and diagonal system, counterbraced. With the exception of those in the flooring, all erection-rivets could be closed mechanically.

The riveting plant consisted of a two-cylinder single-acting

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[1] Annales des Ponts et Chaussées, August, 1890.

pump, driven by a 5-HP. portable engine, an accumulator, a gantry running on the top booms of the main girders, and carry two traversing-crabs supporting two riveters. The pump ha delivery of 3 gallons per minute at a pressure of 3,270 lbs. square inch when driven at 70 revolutions per minute. gantry supporting the riveters was of timber and iron, on wheels, so arranged that one bay of the main girders could riveted up without shifting. On the gantry were two travers trucks, 19·3 feet long, mounted on wheels, and on these a were the travelling-crabs supporting the riveters. The whole hauled along the bridge by means of a winch. The riveters, an opening 1·8 foot wide, and 2·23 feet deep, could exert a press of 41 tons. The Author claims that these riveters required 50 cent. less water than Tweddle riveters.

The following figures are from the Tables given in the Pa The riveters were used through the winter of 1893–4 durin period of ninety-two days, during ten of which no work was d weather and accidents causing delays. Altogether 10,036 ri were closed, or an average of eighty-seven rivets per day per machi The cost of closing a rivet hydraulically was 2·75*d.*, and for ha riveting 1·12*d.* The coke used per rivet, for heating, was 2·2 for hydraulic, and 0·52 lb. for hand-work. The comparatively rate for hand-riveting was due to the smaller rivets, and interruption to the work.

In conclusion the Author is of opinion that the superiority machine- over hand-riveting should lead to the adoption of hydra riveters in bridge-erection. He considers the plant here descri complicated and suitable only for large work, and advocates use of hand-pumps on the girders supporting the riveters. Paper is illustrated by two sheets of drawings, showing a ha power plant, as well as that described in the Paper.

R. B.

Breaking-Test of the Old Bridge over the Emme at Wolhu Switzerland. By F. Schüle.

(Schweizerische Bauzeitung, April 1895, pp. 105 *et seq.*)

The single line railway bridge was built in 1874 on th from Lucerne to Berne over the Emme River at an angle degrees, having a span of 157 feet 3 inches. The main gir the Warren type have box flanges and are about 30 feet de overhead bracing; the diagonals, made of four angle-b a plate, are somewhat eccentrically fixed. In 1891 the was tested with a train equivalent to a distributed load ton per foot lineal, having been calculated for a load of The deflections of the two girders were 1·4 and 1·0 inc tively and the oscillations of the top flanges were $\frac{3}{8}$ inch strengthening of the bridge seemed difficult, the Jur

Company decided to replace the old bridge by a new one and to test the old bridge to rupture. For this purpose the bridge was launched upon one bank of the river, and certain pieces which had recently been added to the diagonals of the web were removed. These preparations being completed in December 1893, the bridge was left to settle till April 10th, 1894, when the deflections under the dead load were found fairly to agree with measurements taken in 1892. On April 13th, six of the eleven panels were loaded from one end with 1·75 ton per foot lineal by means of rails and ballast. On the 17th the same load was extended over the whole bridge. Then, on the suspicion that the diagonals near the middle were weak, four panels were entirely relieved of the load, and on the 24th the load on the loaded panels doubled. When on the 25th the load there had been increased to 4·2 tons per lineal foot, the bridge suddenly gave way without great noise, the height of fall being about 20 inches. The cause of the fall was the buckling of a diagonal in one of the girders, viz., the seventh from the unloaded end of the bridge, under a pressure of 67 tons. The other girder fell immediately afterwards from a similar cause. At every stage of loading, diagrams of vertical and horizontal deflections were taken at the flanges, showing that permanent set had begun with a distributed load of 1·75 ton per foot lineal. The bulging of the diagonals was also measured in two directions, for example, the diagonal which gave way first bulged shortly before the rupture ½ inch in the plane of the girder and ⅛ inch transversely in a length of 30 feet. The diagrams are reproduced.

M. A. E.

Pontoon Bridge over the Düna at Riga. By ADOLF AGTHE.

(Zeitschrift des Vereines deutscher Ingenieure, 1895, p. 39.)

The Düna, at Riga, flows through an alluvial sandbed in a channel which, since the undertaking of the conservancy works, is fairly fixed in position, and varies from 1,500 to 1,800 feet in width. Inundations caused by the ice are now of far less frequent occurrence than formerly; although at the breaking up of the ice —which occurs generally in the early part of April—there is still considerable danger for any structure across or adjoining the river. The surface of the surrounding country and of the banks of the river where the town is built, averages about 33 feet above mean-water level.

The existing railway bridge dates from 1871; but owing to its position above the town, its dimensions, and the frequent interruptions to traffic, it is not well suited to the general requirements of the street traffic of the town. Since the beginning of the last century there has also been a floating-bridge. This consisted of a number of logs carrying a substantial staging—the road-level

being about 12 inches above the surface of the water. This occasioned very inconvenient approaches at both ends; and the continuous surface obstruction to the current checked all floating matter; so that the bridge had to be removed and towed into winter quarters before the ice closed in, and could not be moored in place again until after the breaking-up of the ice in the spring. The effective floating-life of the logs averaged about ten years; after that the timber became so charged with water that it had to be taken out and replaced.

The floating-bridge which has now replaced this raft is of a different type, offering far less obstruction to the current, and, consequently, requiring considerably less mooring-power. It may be described as a series of fourteen rafts, the deck of each being carried clear of the water by resting on two cylindrical floats. Each raft or section of the bridge is 105 feet in length; the two floats or pontoons being 64 feet apart, centre to centre, leaving an overhang or cantilever at each end 20 feet 6 inches long. One cantilever is joined up to the cantilever end of the next section by three baulks about 15 feet in length, laid in parallel grooves in the framing under the roadway and securely screwed down to form a continuous rigid connection, which can at any time be quickly set free again. Two of the spans are arranged for opening to allow of the passage of vessels; and there are in addition two land spans connecting the floating deck with the shore. The total length of the bridge between abutments is 1,720 feet, and the width between parapets is 45 feet 10 inches, of which the roadway is 35 feet 4 inches, and two footways 5 feet 3 inches each.

The pontoons are of boiler-plate, measuring 85 feet 6 inches in total length, and of elliptical section; 10 feet 6 inches wide on the minor or horizontal axis, and 12 feet 1½ inch high on the major (vertical) axis. Each end terminates in a sharp nosing of substantial construction, to withstand the impact of ice or any other floating object; and the cylinder is divided into five compartments divided by solid bulkheads so as to form separate water-tight sections. The mooring-chains, weighing 22 lbs. per lineal foot, are stretched diagonally under the pontoon; the up-stream chain being secured to the top of a 5-inch diameter wrought-iron screw-pile 10 feet in length, sunk in the bed down-stream or below the bridge, while the down-stream chain is secured to a similar pile on the up-stream side. This arrangement gives great steadiness under all conditions, as there is no tendency of floating matter to press down or force up the chains or tilt the bridge. The total floating width of the pontoons is only about 6 per cent. of the width of the channel, and the road-level is about 12 feet above the water, so that there is ample clearance for ice.

The deck is carried on four longitudinal and parallel trellis-girders, with cross-bracing. The rigidly-secured baulk connections distribute the load longitudinally, from one section to another, so as to form practically a continuous-girder bridge. The weight of

each pontoon is 22·3 tons, and its floating capacity is about 180 tons. The weight of the superstructure does not exceed 60 tons, which is equivalent to 0·58 ton per lineal foot. The live load is taken at 82 lbs. per square foot on the roadway, and 115 lbs. per square foot on the footways.

P. W. B.

A Novel Swinging Foot-Bridge.

(Engineering News, New York, January 24, 1895, p. 51.)

This article refers to a temporary foot-bridge which was erected to take the traffic during the time occupied in repairing a permanent wrought-iron swing-bridge carrying the traffic of Fourth Street across the Mission Creek Channel in the city of San Francisco. The permanent swing structure having been turned into the open channel position and blocked up for repairs on the turntable pier, the temporary crossing was formed by a timber fixed-span structure from one shore to the turntable pier and the timber swing-bridge in question, from thence to the other shore.

The article is illustrated by a general view and diagrams of details. The bridge consisted of a pair of single counter-diagonal trussed frames, about 6 feet apart and 62 feet long, with bottom booms of single timbers of that length. The pivot-pier was formed by a raking pile at an inclination of 1 in 20 from the vertical; its total length was 100 feet, and it was driven for a length of 35 feet in soft mud, leaving the top 40 feet above the level of the wharf platform, against which it was strutted. The pile was stayed by three-wire guy-ropes of $1\frac{1}{16}$ inch in diameter ($3\frac{1}{4}$ inches in circumference), the back one being adjustable by a screw-coupler or turnbuckle. The top of the pile, 16 inches in diameter, was bound with an iron ring, and a $2\frac{1}{2}$-inch pin, 4 feet long, was let into the pile for a depth of 2 feet 6 inches.

On this pin worked a swivel resting upon a layer of four iron rings, thoroughly oiled so as to work smoothly. To the swivel was attached the wire ropes of $\frac{5}{8}$ inch in diameter (2 inches in circumference) supporting the outer ends of the bridge. The guy-lines were attached to a cap and ring made of 3-inch gas-pipe, fitting over the head of the pin, above the swivel. Wire ropes of $\frac{5}{8}$ inch in diameter (2 inches in circumference) also supported the end of the bridge which butted against the pile, and a semi-circular recess was cut out of the cross-beam of the bridge at that point so as to form the turning joint, in conjunction with a series of rollers attached to the pivot-pile at wharf-level, this joint being protected above by a cover of $\frac{1}{4}$-inch plate. The bridge was opened from the shore by one man at a windlass, and, owing to the inclination of the pile, was raised at the outer end, similarly to a swinging gate, returning by gravity to the closed position as soon as the windlass was let go. The strain of the supporting

cables was partly relieved by a lever 16 feet long of 8-inch by 8-inch timber, planed and greased, the one end being blocked up 12 inches above the level of the other, so that when the bridge closed across the channel the velocity of the end was sufficient to carry it up this inclined plane, which was then raised into a horizontal position and blocked up securely by means of a hand-lever. This bridge was in use for three weeks, the time occupied in repairing the permanent structure, and worked satisfactorily throughout.

D. G.

Taking Cross-sections on the Upper Rhine. By — AUTENRIETH.

(Zeitschrift für Vermessungswesen, 1895, p. 217.)

Taking cross-sections on the Upper Rhine, especially on the section between Basel and Lauterburg where the current is very powerful, necessitates much care and experience in that class of work. As many as twelve to sixteen watermen and workmen are required, and they are divided into two parties, one for each bank. The Rhine has an average width of 250 yards. The current, even when the water is at the mean level, is very great, and there are numerous shoals. The rapids are 8 to 10 yards in depth.

The wire rope employed must be at least 280 yards in length, of suitable thickness and provided with marks. Even when it is merely a question of surveying a portion of the bed of the river, the rope must always be stretched across the whole river, and at each end a length of thick cable has to be provided so that it can be fixed on both banks. It is first fixed on one bank and then taken across to the opposite bank and there fixed to a tree. Carrying over the rope is an operation not unattended by difficulty because it often gets caught in old tree-trunks, rocks, &c., and must be got clear by aid of the men in a boat. It can, too, only be taken across the water when the conditions are specially favourable, and this is rarely the case. The installation and anchoring of several skiffs on which the rope can be laid is both difficult and dangerous, because the anchors after a short time become so firmly embedded that they cannot be raised.

Another difficulty is that the section has often to be taken in places where the banks are low. It is absolutely necessary to have in reserve a supply of material so that the work is not interrupted on account of unforeseen events. The piles must be in proportion to the depth, and they must be heavy at the base, otherwise the force of the current will prevent their reaching the bottom. The method of surveying is similar to that usually adopted for rivers, except that in this case piles must be driven in every 4 or 5 yards. In order to obviate accidents, the boat containing the workmen must not be held by a line during this operation. Moreover the wire rope must be fixed in such a way

that as soon as a steamer, sailing-boat, or raft appears in sight, it can immediately be removed. As the section must be drawn for a given water-level, it is necessary to determine the level of the water several times a day by reference to the nearest bench-mark.

B. H. B.

Note on Improvement Works in the Meuse in and above Namur.

By E. Marote.

(Annales de l'Association des Ingénieurs sortis des Écoles spéciales de Gand, 1894–95, p. 201.)

This Paper describes some important works which have been lately carried out in the bed of the Meuse, with the object of improving the flow of the river, and of facilitating navigation.

These works consisted principally of modifications and rectifications of the river banks, and deepening of the channel. At Beez a single channel 328 feet wide on the bottom was substituted for several shallow channels and islands which formerly existed, and a refuge basin, 984 feet long, 164 feet wide, and 11 feet deep was constructed for the protection of vessels during floods. At Grands Malades and Maizeret larger locks were built, 328 feet long by 39 feet wide, in place of the old ones, which had a length of 182 feet 6 inches, and a width of 29 feet 6 inches. Here also new sluices were constructed, and all these works are described in detail. The river banks, where modified, were protected by stone pitching.

A large portion of the Paper is devoted to a very detailed consideration of the cost of dredging and the disposal of the spoil, 1,078,900 cubic yards being removed at an average inclusive cost of 9·55*d.* per cubic yard. The following figures are taken from the very detailed tables that are given. The Author assumes that important plant, such as dredgers, locomotives and other machinery, has a life of twenty years, while wagons, rails, timber, and other minor plant have a life of only five years. He also takes 150 as the average number of working days per year. Taking interest at 5 per cent., the sinking fund and interest on capital amount to 10 per cent. of the first cost of the former description of plant, and to 25 per cent. of the first cost of the latter.

At Grands Malades the dredged material was tipped direct into 4-yard wagons run on to a barge alongside the dredger; the wagons were hauled up an inclined plane on to the bank by a wire rope, thence by a locomotive and tipped close by, at an average height of 13 feet above mean water-level. 85,600 cubic yards were removed in this manner, at a cost of 12·8*d.* per cubic yard. 18,700 cubic yards of material were discharged direct into barges which were towed to Beez, 1·86 mile from Grands Malades, and the spoil shovelled out into the river-bed at a cost of 8*d.* per cubic yard.

At Beez, the dredgers discharged 317,850 cubic yards into barges

which were towed to the channels which it was proposed should be filled up; some of these barges delivered the spoil into the river through hopper bottoms, while others were emptied by means of a floating elevator, discharging either on the shore or into the river. This method of disposal cost 5·82*d.* per cubic yard.

At Brumagne and Maizeret the dredgers discharged into barges which were towed about 1¼ mile to Beez, and the spoil was raised and deposited on shore at an average height of 13 feet above mean water-level by means of floating elevators. A suction pump was tried; but owing to the clayey nature of the spoil, its efficiency was inferior to that of the elevator. The 361,130 cubic yards disposed of in this manner averaged 6·33*d.* per cubic yard.

Arguing from the figures given, the Author urges the superior economy of elevators and barges as compared with locomotives and wagons or hand work in dealing with excavated material on large works of a nature similar to these improvements of the Meuse.

R. B. M.

The Navigability of the Red River (Tonkin).

By Lieut. Léon Escande.

(Revue Maritime et Coloniale, vol. cxxvi., July 1895, p. 63.)

The search for the best methods of opening up the trade of China has led to many expeditions in recent times, and the conquest of Tonkin had been achieved mainly with the object of securing for France the easiest and most direct access to the vast populations which exist in the centre of the continent of Asia, isolated, it may almost be said, from the rest of the world. The Author having spent six years in Tonkin, and having carefully studied the works of Commanders Bugard and Le Prieur, had become convinced that the Red River was navigable throughout the year for vessels of light draught, and having submitted his views to the authorities received permission in the course of 1893 to verify his theories by explorations on board the gunboat "Moulun," commanded by him. A general outline is given of the course of the river, and for this purpose the Author divides the stream into three sections, first, the delta from the sea up to Victri, the confluence of the Red River with its two principal tributaries, the Black River and the Clear River, a length of about 164 nautical miles; second, the region of the shifting sands from Victri up to the first rapids at Tach-Tuch, 11 miles above Yen-Baï, hitherto regarded as the highest navigable point for steamers, a course of 95 miles; third, the region of rocks and pebble-strands from Tach-Tuch to Lao Kaï and the Yunnan frontier, a stretch of about 115 nautical miles. With respect to the first of these sections he has nothing to impart, beyond the fact that it has been officially surveyed and that steps are about to be taken to improve the channel so as to enable large vessels to enter the port of Haïphong. Respecting the section from Victri to the first rapids,

he states that this portion presents the chief obstacles to navigation in the dry season, if there were no means for securing sufficient depth of water to surmount the various shoals, which sometimes extend right across the river, and which, in spite of an ample flow of water, render the utmost available depth in places only from 20 to 24 inches. He points out the method adopted by the natives in other localities, where the rivers are shallow. This consists in the employment of fascine-work and dams, brought out from whichever bank is found to lend itself best for this purpose. It thus becomes possible to confine the water in a narrow channel against the opposite bank, giving sufficient depth to assure the passage of their boats. This plan could, he thinks, be employed with success in the Red River. The third section above Yen-Baï abounds with rapids to the number of thirty-three between Yen-Baï and Lao-Kaï. These rapids are caused by obstacles of two kinds—rocks and pebble-banks, and the Author considers that the latter might be almost entirely removed by suitable blasting operations. By reference to a chart, he explains the works needed at the rapids of Thach-Haï, which are typical of those encountered in this section. Careful surveys have been made of the channel, and charts of soundings have been prepared, using as a datum the low-water mark at Lao-Kaï. Detailed accounts are given of two voyages up the Red River on board the "Moulun" in 1893 and 1894. As the result of three voyages undertaken for the purpose of this exploration, the Author asserts that the Red River is navigable throughout the year for boats with a speed of from 8 to 10 knots, and having a draught not exceeding 40 inches, while for six months in the year vessels drawing 6½ feet of water might, if their speed attained 10 or 12 knots, reach the furthest limits of Tonkin.

G. R. R.

The Santa Ana Canal of the Bear Valley Irrigation Company.

By W. H. HALL, M. Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, February, 1895, p. 61.)

The object of the Santa Canal is to deliver water for irrigation and domestic use throughout about 45,000 acres of land in the northern portion of the San Jacinto Valley in the county of Riverside. The project has been in contemplation for many years, but temporary means have been adopted to postpone its execution. These involved the driving of the Moreno Tunnel, 2,300 feet long, through the San Timoteo Hills, on the north side of the San Jacinto Valley, of the capacity ultimately required, and the laying of a line of pipes, 10 miles long, from the Mill Creek, capable of carrying 18 cubic feet per second. In 1891 the owners of this stream refused to continue the agreement; consequently, the scheme had to be commenced and so arranged as to maintain the supply after the termination of this contract. It was, therefore,

necessary to so locate the line of the aqueduct that it could discharge into the line of pipes referred to.

The source of the supply is the natural flow of the Santa Ana River, supplemented during the irrigation months by water from reservoirs on the aqueduct impounded during periods of floods. The distance from the intake to the head of the line of pipes is 5½ miles, and it is this portion of the aqueduct that has been completed. The flow of the Santa Ana River varies from a few cubic feet per second to 20,000 cubic feet per second in extreme floods. The canal was designed to deliver 200 cubic feet per second, but portions of it carry as much as 300 cubic feet per second in order to fill the reservoirs on the line from the floods of the rivers or streams which are crossed.

About 2½ miles of the aqueduct consists of flume, 2½ miles of canal and tunnel, and the remainder of pipes.

At the intake a dam 3 feet higher than the mean level of the boulders in the river-bed is built across its course and blocks up the water, so that it passes over weirs of variable height into the conduit. Means of sluicing away any deposit on the river side of the weir is provided. The flumes are of the stave and binder type, with rounded bottom and straight sides, 5½ feet wide and 5½ feet high, but only completed at present to half capacity. The bottom consists of a centre stave 9¾ inches wide, and sixteen others, each 5¾ inches wide, all 1¾ inch thick. Planks of the same thickness form the straight sides. Each stave has ⅛ inch bead on its edge to press into the next one. Stiff ribs are introduced every 8 feet, to which the vertical side planks are firmly secured, so preventing any inward buckling. Between the frames two binding-rods of ⅝ inch round mild steel, screwed at the ends, pass under the flume and through cross-heads 3 inches by 4 inches placed across it on the top. The ribs are made of iron tee-bars, 2¼ inches by 2¼ inches, bent to the form desired and connected with a cross-head in the same way as the rods, and rest on timber sills carried on a concrete foundation or wooden trestles as required by the nature of the ground. One of the tunnels is singular in being constructed at such a level as to always stand full of water, and being lined with 3-inch wooden staves firmly wedged together, and packed behind with concrete.

The pipes are of the wooden stave and rod binder type,[1] and, like the flumes, laid on the surface of the ground. They are 52 inches diameter, and only one line is at present laid. It is calculated to deliver 120 cubic feet per second, and made 2 inches thick with a head of 50 feet, 2·3 inches with a head of 100 feet, and 2·6 inches with greater heads. With the former thickness it can be laid to curves 250 feet radius, and with the latter to 300 feet radius, by bending the staves after they are in position.

A. W. B.

[1] Minutes of Proceedings Inst. C.E., vol. cxvii. p. 430.

The Construction of the Third Wet-Dock at Rochefort.

By Crahay de Franchimont.

(Annales des Ponts et Chaussées, May, 1895, p. 459.)

This Paper deals with the construction of the third wet-dock at Rochefort, which was commenced in March, 1882, and completed in May, 1890. The Paper is divided into four parts:—(i.) The earthwork and masonry; (ii.) the metal-work in the lock; (iii.) the machinery for working the lock; and (iv.) a criticism of the whole installation.

(i.) The dock is in shape a rectangle, joined on one of its short sides to an irregular pentagon, on the opposite side of which is situated the lock, this shape being due to the position of the dock on the right bank of the Charente between the railway station and the suburb of Cabane-Carrée. The total length of the quay-wall is 1,112 yards, while one side, 175 yards long, is occupied by a pitched slope (thus allowing of future extension in this direction), in the centre of which is a timber slip 55 yards long for handling Baltic timber. The area of the dock is 16 acres. The lock is 535 feet 3 inches long, and 59 feet wide, with four pairs of gates, in two-sets, opening in opposite directions, with a minimum length of 343 feet 9 inches between them. Provision has also been made for an intermediate pair of gates, which can be added hereafter, for locking in small vessels. The level of the sills is 19 feet 8 inches below the standard level of France (datum) or 13 feet 1½ inch below the lowest recorded tide at Rochefort. This gives a depth on the sills of 30 feet 6½ inches at high water of spring tides, and 25 feet 5 inches at neap tides, with never less than 23 feet 4½ inches at high water. The depth inside the dock is 3 feet 3 inches less than on the sills, allowing for deepening hereafter if required.

The lock is spanned by a swing-bridge, carrying the roadway to Cabane-Carrée. The lines on the quays have no curves of a less radius than 328 feet, and the rails next the dock are used for travelling-cranes. Water is supplied by a 2·67-inch main at 28·4 lbs. per square inch pressure.

The whole of the dock walls are carried on masonry piers 30 feet apart, 16 feet 5 inches wide, and 26 feet 3 inches thick from face to back. Every fourth pier is strengthened by another behind it, these two being 19 feet 8 inches square, and 3 feet 3 inches apart. The piers at the angles also vary in size. At a level of 10 feet 6 inches below datum the piers are connected by arches, and dry-stone slopes, resting on other arches between the piers, are filled in under them. The walls are backed with dry-stone walling of such a thickness as to take the pressure of the quay filling off the walls proper. The counterfort piers are connected to those in front of them by semi-circular arches 19 feet 8 inches below datum, and also by old rails bent and built in. The dock was only excavated to 4 feet 1 inch below datum before the

water was admitted, the remainder being removed by dredging. The piers were built hollow, and compressed air was used to complete the sinking of nearly half of them.[1] They rested on a bed of sand from 75 feet to 85 feet below datum, giving a total average height to quay-level of about 98 feet. In places where the ground was very soft, the dry walling at the back was supported on timber platforms.

The walls of the lock are of the same construction as the dock-walls, and the floor is also carried on similar piers, the whole being connected together by arches below the level of the lock floor. A culvert is taken across the lock in the side walls and under the floor for the gas- and water-mains. The sills are of granite, straight, and with a meeting angle of 137° 30′. The wing-walls at the lock entrance are similar, but the piers are carried on piles, and where these have not been driven down to the sand, the load on them is calculated at 205 lbs. per square foot of the surface of the pile. A culvert is carried all round the dock in the thickness of the walls for the gas- and water-mains. The ground, down to the foundation of the piers, was an impervious silt, and there was thus no trouble with water.

(ii.) There is nothing very special in the metal-work. The swing-bridge is sufficiently strong to take a line of rails if required, and it and the gates are of iron or steel. The gates have ten horizontal frames with vertical stiffeners, and covered with plates. The lower sections are water-ballasted, so as to give each leaf a weight in water of 11,000 lbs., and are made water-tight with cement. The sluice-shuttles are 6 feet 1½ inch high and 6 feet 6½ inches wide, running in cast-iron grooves, and designed to take pressure in either direction.

(iii.) The swing-bridge, gates, and sluices, are all fitted with hydraulic machinery as well as hand-gear. Water is supplied by the mains from a tower in two divisions, each with a storage capacity of 200,000 gallons. This tower also supplies Cabane-Carrée, and the villages of Pont-neuf and Pont-rouge. The working pressure is 28·4 lbs. per square inch, and the cylinder relief valves are loaded to 42·6 lbs. per square inch. The swing-bridge is raised off its pivot and blocked up by means of two short cranks which rise under the tail of the bridge when rotated by means of a pinion and a rack, the latter being attached to the piston-rod of the hydraulic cylinder. The gates are opened and closed by means of a pivoted double-acting cylinder, the piston-rod of which is connected direct to a tail-piece attached to the heel-post. The sluices are raised by screws actuated by gear and racks.

(iv.) The Author criticises the methods and details of construction in the light of the experience gained since 1882. He approves of the entrance to the dock being constructed so as to point down stream, and also of the form of the dock walls. He

[1] The method of sinking these piles is fully described in the Annales des Ponts et Chaussées of February, 1884.

points out the advantage of removing the lower portion of the dock after the water is admitted, both on account of economy and the lessened tendency to movement in the walls. He recommends that if there is any probability of having to use compressed air for sinking the piers, these should be shod with iron, the extra cost being small, and the facility of sinking greatly increased. He does not recommend the culvert in the body of the walls; it cannot be kept water-tight, and weakens the walls. He approves of the construction of the gates, but states that the lifting-gear for the bridge is not efficient. He is not in favour of the form of bollard used; the necessity of fixing these before finishing the coping sometimes preventing this from being kept straight, owing to settlement after the bollards were fixed.[1] Finally he points out the advantages of a low-pressure hydraulic power system in a port of secondary importance like Rochefort.

The Paper, which extends over 140 pages, is accompanied by a very complete set of Tables of the cost of the various descriptions of work and materials, and is followed by an Appendix, giving the calculations for the stability of the walls and the dimensions of the machinery. In addition to several illustrations in the body of the Paper, it is accompanied by a view of the opening ceremony, five sheets of details of the masonry in the lock and dock, and two sheets of machinery and ironwork details.

R. B. M.

The Puget Sound United States Navy Dry-Dock, Port Orchard, Washington State.

(Engineering News, New York, January 24, 1895, p. 50.)

Full details of the original design for this dock, constructed principally of timber, were given in an earlier number of the same journal.[2] In execution some departures from the design have been made, but not to any considerable extent. One of the principal alterations is the lengthening of the dock by 50 feet, the better to accommodate the large express steamers which in case of war might

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[1] These are fully described in the Annales des Ponts et Chaussées for May, 1883.

[2] In *Engineering News* of May 19, 1892, the following are given as the principal dimensions of the then intended dock:—

	Ft.	Ins.
Length on coping head to outer end of table	625	3
„ „ „ gate	605	9
„ floor, head to inner abutment	529	3
Width on coping at body	130	1½
„ „ abutment	92	8
„ floor in body	67	1½
Depth, coping to mean high water	7	0
„ „ floor in body	39	3
Draught over sill at mean high water	30	0

be chartered by the Government. The caisson gate has also been somewhat modified, and as constructed is of the following dimensions, viz.,

	Ft.	Ins.
Length over all	91	10⅜
Extreme moulded breadth	24	0
Moulded breadth at top	13	0
Extreme height	38	11½

The two concrete, stone-faced wings at the entrance to the dock are to be eventually extended to a length of 500 feet, with a distance of 180 feet between them. The dimensions of the principal timbers actually used in construction are as follows: the longitudinal caps on the piles, 12 inches × 12 inches, secured by ⅞-inch drift bolts, driven 12 inches into the piles. Crossing these caps are 14-inch × 16-inch transverse timbers, each 72 feet long, extending clear across the dock. The piles supporting the inclined sides of the dock are capped by scantlings of 10-inch × 14-inch butting against the transverse floor timbers. The altars are made of 11-inch × 11-inch scantlings, secured to these inclined caps. As a further means of keeping out the water, a row of sheet-piling was driven around the floor of the dock 5 feet to 6 feet into the undisturbed soil, and rising 10 feet above the floor and behind the side slopes of the dock. Outside the outer row of piling a row of sheet-piling was also driven. At the back of the altar braces 3 feet of puddled clay was well rammed in.

The drainage plan is as follows, viz., resting upon the natural soil under the timber grillage surmounting the piles is a network of square wooden box-drains, leading to a central 12-foot circular brick culvert, emptying into the sump in the pump-house. Above this system of drains is a bed of Portland cement concrete, nowhere less than 3 feet thick; and in this concrete are surface drains 6 feet wide, leading to the cross drains and culvert described. The floor of the dock runs lengthwise, and is made of 3-inch × 12-inch planks laid with ½-inch spaces between them to allow the water ready access to the drains beneath.

As regards the caisson gate, it consists of a double-ended hull built entirely of steel, provided with an upper deck of wood and a main and lower deck of steel; and there are also two sets of transverse beams without decks. Running the entire length of the keel are two steel 5-inch × 4½-inch angles, spaced 10 inches apart, and holding between them a 6-inch × 10-inch creosoted packing timber, and secured to this timber by copper nails is a rubber packing-piece, oval on top and having a base of 6 inches. When in position this packing is pressed against the stone sill provided at the dock entrance by the pressure of the water from without when the dock itself is empty.

This caisson is provided with twelve 20-inch filling culverts passing through it and controlled by gates on the main deck. The water-chamber situated between the main and lower deck has two 20-inch sluices, one connecting with the sea and the other with

the dock, also controlled by valves on the main deck, on which is a small engine and centrifugal pump, for emptying the chamber, capable of delivering 2,500 gallons per minute. The ballast is of cement and pig-iron; and the caisson is manœuvred by a capstan on the deck in the ordinary manner. The dock when full contains 13,000,000 gallons, and with the pumping plant provided can be emptied in two hours. The cost of the dock, which will probably be completed in the August of 1895, or nearly one year earlier than the time stipulated for in the contract, will amount to about £124,630 ($607,951).

The article is illustrated by six photo-lithographed views.

D. G.

The Purification of the Seine by the Distribution of the Sewage-Water over the Plain of Achères.

(La Revue Technique, July 25, 1895, p. 321.)

Upon the almost unanimous advice of the experts consulted by them, the authorities of the City of Paris decided to employ their sewage-water in broad irrigation and, as is well known, the peninsula of Gennevilliers, formerly a barren waste, has in the course of some twenty-five years been by this means converted into a fertile market-garden. The only serious objection hitherto raised against this mode of disposal has been the insufficiency of the available area for the treatment of the whole of the sewage-water, and it is on this account that additional waste lands have recently been acquired at Achères and elsewhere for sewage-treatment. The first irrigation experiments with the Paris sewage were made as far back as 1869, and the chief pumping-station at Clichy has been in operation since 1873. As subsequently extended in 1881, these works were capable of raising 20,000,000 gallons of sewage in ten hours. When the extra land at Achères was obtained in 1892, it became necessary to provide additional pumping-power to lift the sewage to a height of 159 feet for its conveyance to the new property at a distance from Clichy of some 8 or 9 miles. A lift of this kind could only be obtained economically with piston-pumps, but there were grave objections to carrying on this work at Clichy in the existing pumping-station, situated in the midst of a dense and growing population, as any accident to the rising main, running under a considerable pressure, might give rise to serious inconvenience. Mr. Bechmann, the chief engineer of the City of Paris, therefore resolved to traverse this populous district by gravitating sewers, and the sewage-water for Achères would by this means be merely raised at Clichy for conveyance to a second pumping-station, situated at Colombes. The lift thus required at Clichy is only 21 feet, while the existing distributing mains for the area at Gennevilliers involve a lift at Clichy of 44·6 feet. This pumping is all effected by means of centrifugal Farcot-pumps,

which for similar lifts give much better results than the best plunger-pumps. Detailed descriptions are given of the new installations at Clichy and Colombes for the execution of these works and the machinery is explained by reference to plans, photographs and diagrams. The sewage raised at Clichy for conveyance to Achères is received at Colombes into strainingt-anks where the suspended impurities are deposited and the floating matters are removed by screens. The pumping-station at Colombes, which will be hereafter largely extended, comprises at the present time one horizontal piston-pump, one horizontal centrifugal pump with four "distributors," and two tubular boilers. The former pump, at thirty-five revolutions per minute, will lift 110 gallons per second to a height of 137 feet, and at twenty-eight revolutions the estimated yield is 88 gallons per second. The centrifugal pump is capable of lifting 1,584,000 gallons per hour to the prescribed height of 137 feet. On quitting the pumping-station at Colombes, the sewage is conveyed across the Seine by means of an aqueduct in the form of an iron bridge in three spans, the sewage being carried in four mild steel pipes, each 43·3 inches in diameter, placed below the roadway. After crossing the river it is lifted in rising-mains of mild steel plate to the compensation-reservoir at the summit-level. A section is given of the whole course of the outfall, and there are also details of the various forms of concrete and iron tubes used in the work. G. R. R.

Some Processes for the Purification and Sterilization of Potable Waters. By Georges Michel.

(Bulletin de la Société Scientifique Industrielle de Marseille, 1894, p. 265.)

It is pointed out that all the available service waters of Marseilles, when considered from the point of view of their contents in bacteria, are bad, yielding as they do on analysis from 500 to 15,000 germs per cubic centimetre. The only exceptions are the artesian well waters of St. Ferréol and a spring in the Place du Grand-Puits, which both contain less than 200 bacteria per cubic centimetre. If by any accidental contamination emanating from the large population alongside the Marseilles canal or the Merlan-Longchamp supplies, typhoid fever or cholera germs passed into these waters, it is quite probable that these diseases might be introduced into all parts of the city. In order to minimize these risks, it is suggested that the water should be conveyed in a covered channel, and that the "Anderson" purification process should be employed. Reference is made to another source of supply available, namely, some underground streams which have recently been intercepted while a tunnel was being constructed by the Colliery Company of the Bouches-du-Rhône. These springs are clear and palatable; they are also tolerably abundant, yielding about 154 gallons per second. Analyses are given of the water in

question, as also of some of the existing supplies, and the Author points out that it is urgently necessary to purify the water now in use. The various methods of effecting this and of destroying the germs are discussed. The processes are dealt with under four heads:—(1) Sterilization by heat; (2) Sterilization by the employment of soluble antiseptics; (3) The precipitation of the matters in suspension and incidentally of the living germs in various ways, this process being generally followed by imperfect filtration through coarse filters; and (4) Simple filtration. Each of these systems is described at some length. The apparatus of Geneste and Herscher may be used if heat is to be the agent selected. Dr. De Christmas has advocated the employment of citric acid, if a soluble antiseptic is to be made use of. This acid paralyses cholera germs if used in the strength of 4 parts per 10,000, and if a solution of double this strength is employed it is absolutely fatal to germs. Under the third head of a mixed precipitation and filtration process, it is pointed out that the results thus obtained are incomplete and are not reliable. Treatment by Clark's process for the removal of excess of lime, and the plans advocated by Messrs. Gaillet and Huet, as also Anderson's process, involving the use of iron, are described. This last system has been suggested and is about to be tested experimentally. Passing on to the fourth head, sand-filtration is shown to be the best method under all circumstances, on a large scale. For perfect results the use of the Chamberland filter is needed, and details are given of the working of this apparatus by reference to diagrams; the form employed being that fitted with André's scrapers, and the pressure regulator of Messrs. Samain and André.

G. R. R.

Line of Pipes under the Willamette River, Portland, Oregon.

By F. Riffle and A. S. Riffle, MM. Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, April, 1895, p. 257.)

This line of pipes forms part of the main pipe-line constructed during 1893 and 1894 to supply the city of Portland with pure water diverted from Ball River, a mountain stream about 30 miles distant. The greater part of the pipes are 32 inches diameter, but the pipes for the river-crossing were made 28 inches diameter, of cast iron, $1\frac{1}{2}$ inch thick and 17 feet long. The length of pipes required to cross the river at low water is about 2,000 feet. The spigots were turned to a spherical surface 20 inches radius outside, and the inside of the sockets are concentric of $\frac{3}{8}$ inch greater radius. After the spigot of one pipe was inserted into the socket of the adjoining one, a ring 3 inches deep, the inside of which was turned to the same spherical surface as the inside of the socket, was bolted to the latter, so as to prevent the withdrawal

of the spigot, and lead was run into the space between spigot and socket.

The trench for the pipes was dredged; it varied in depth from 8 feet to 23 feet, with a bottom width of about 10 feet; the material consisted of mud, sand, gravel and boulders. Some of the pipes were found, before laying, to have sockets and spigots not truly spherical, and the contractors were only allowed to use them on the understanding that they took the responsibility of making the joints watertight.

For laying the pipes in shallow water near each bank, trestles were erected, one over each pipe, from which the latter were suspended and gradually lowered into position by 1¼ inch diameter screws.

For laying in deep water a cradle constructed in the form of an inverted bowstring girder bridge was used. One end was supported on a pivot between the bows of two barges 10 feet apart; and the other end, by long rods, between their sterns, so as to allow the cradle just to touch the bottom of the trench. The weight of the pipes in the cradle tended to push the barge forward, its advance being regulated by lines from the stern of the barges connected to the pipes already laid. The barges were kept in line by ropes round a row of piles above the pipe trench 35 feet apart. The line of pipes was tested by hydraulic pressure about every 200 feet laid to a pressure of 200 lbs. on the square inch, and by this means the joints were practically caulked by squeezing the lead between the sockets and spigots; any leaks were caulked by a diver.

A. W. B.

Boring Operations for Improving the Schönborn Spring at Kissingen. By — KÖBRICH, of Schönebeck on the Elbe.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, 1894, p. 335.)

The Schönborn artesian well in Hausen near Kissingen is one of the chief springs in this spa. This and the so-called round Brunnen supply most of the saline water used at the Royal Baths, and also at the new baths in the Kissingen Kingarten, to which it is delivered through pipes some 4 kilometres in length. The drinking water is mostly drawn from the old springs Rakoczy, Pandur, and Max.

The Schönborn spring rises from a considerable depth. The first borehole was put down in 1882 to a depth of 211 feet. At this depth a spring of saline water, weakly charged with carbonic acid was tapped. In the period from 1831 to 1854 the hole was put down to a depth of 194 feet, and two more springs tapped, containing about 10 per cent. of salt and rich in carbonic acid, so that the water is delivered at considerable pressure, and in a milk-white jet at the surface. The depth from the surface of the three springs tapped is respectively 211 feet, 1,194 feet, 1,618 feet.

In 1865, upon the advice of Professor Scheerer, the lower spring (which was so highly charged with carbonic acid, that at times the water would be driven up 30 feet above the surface), was closed with a cement plug reaching to a point 1,359 feet below the surface, as he feared the violent action of this spring might injure the others. After this was done it was found that the temperature of the water fell from 68° F. to 65° F., that the percentage of salt in suspension was less, and the supply, which in 1866 amounted to 202 gallons, had fallen in 1875 to 160 gallons, and in August 1890 only amounted to 66 gallons per minute, or not sufficient for the supply of the baths.

In 1851 a gun-metal tube 5¼ inches bore and $\frac{1}{16}$ inch thick had been inserted in the well to shut out the water from the first spring, which contained but a small quantity of carbonic acid. For various reasons it was obvious that this tube no longer fulfilled the purpose for which it was originally intended, and the Author of the Paper was called in in October 1892 to examine and report to the authorities what could be done to improve and increase the supply of water.

After carefully examining the matter he decided that the old gun-metal tube must be removed, and a wooden one inserted in its place, and to thoroughly open up the whole down to the 1,195 feet level. For this purpose a complete well-boring plant had to be installed. In order not to interfere with the water-supply, the work was not taken in hand till after the bathing season. The first trials were made between February 17th and April 22nd, 1893, steel augers and diamond drills having to be used to remove the gun-metal lining pipe, which was found to be so much worn that it could only be pulled out in short pieces at a time, and that with great difficulty. It was found impossible to remove all this tube in time for the approaching bathing season, and it was accordingly decided to temporarily line the hole to a depth of 288 feet with an iron pipe 4½ inches internal diameter, ¼ inch thick, and as the well had ceased to flow, to put down a drill with a 3⅞-inch diamond crown to a depth of 1,323 feet, to clear out the dirt and small pieces of gun-metal. To start the water flowing, a small pump reaching down to the level of the lower spring was used, and as the water became more charged with carbonic acid gas and the water pumped down for the drills was removed, it at last commenced to flow over the top of the well of its own accord. The quantity increased from 73 gallons to 110 gallons per minute at the end of the bathing season.

The work of re-lining the well to shut out the top spring and enlarging the bore to the second spring was again taken in hand on the 14th of October, 1893, and after many difficulties carried to a successful conclusion in March 1894. The water-supply was in this way increased to 143 gallons per minute, and the temperature to 68° F.

The Paper is accompanied with numerous illustrations of the well and tools employed. R. E. C.

Destructor-Furnace Experiments at Berlin.

(Gesundheits-Ingenieur, July 15, 1895, p. 212.)

The municipal authorities of Berlin having voted a sum of £5,000 for experiments with the combustion of the town dust and ashes, on the systems of Messrs. Horsfall of Leeds and Warner of Nottingham, the necessary tests have been carried out under the special direction of Councillor Bohm and Mr. Grohn, Government architect. The requisite buildings were erected on the premises of the old waterworks at the Stralau Gate, which have been discontinued since 1893. The new process has been in operation since the end of November, 1894. As the intention was to try each system separately the two processes were kept entirely distinct, and though one chimney, which was already on the site, served for both sets of furnaces, each plant was provided with a special flue. There were two chambers or cells on the Horsfall system and three on that of Warner; these were so arranged that additional furnaces could in either case be erected, and provision was made on the Horsfall destructor-flues for the subsequent insertion of a steam boiler, to be heated by the residual gases. In order that the furnaces should be properly stoked an engineer from the waterworks and a skilled fireman were sent to England to learn the needful working arrangements on the spot, and on their return they were to instruct the staff; moreover, Mr. Warner, one of the patentees, came over for several days to take charge of his branch of the operations. The Horsfall Company sent over their engineer for a week and a skilled fireman for a month. The experiments have been carried on continuously day and night, with the exception of a few weeks at the beginning of the present year, when the process had to be stopped for the repair of the chimney. As the works were only provisional it was not considered necessary to construct a regular loading-platform with inclined gangway, but the furnaces were fed by means of a small crane.

It was at first decided to deal with the refuse on the English system, just in the state in which it came in, without admixture with fuel, and these tests extended over several weeks during December, 1894, and February, 1895. This plan proved, however, unsuccessful, and the furnaces in nearly all cases became extinguished in from 4 hours to 5 hours after they were filled; exceptionally they kept alight for 8 hours, but even when the chambers were heated to bright redness before beginning the work, and when skilled workpeople were engaged, it was impossible to keep the furnace going for any length of time. It was then resolved to mix the refuse with coke to avoid, as far as possible, the production of black smoke, but as smoke was not perceptible coal was employed later. The amount of extra fuel added in some cases rose to 10 per cent. by weight. The results were not satisfactory, as much of the added fuel was not properly consumed,

but came away in the form of cinders. The system worked better when the extra fuel was first ignited in the ashpit and then distributed, when fully alight, among the contents of the destructor-chamber. The temperature of the products of combustion in the flues, which was ascertained continuously with a pyrometer, was notably lower than in similar works in England, being generally from 120° C. to 150° C. and rarely reaching 200° C., whereas in England the corresponding temperature rarely falls below 200° C. and often attains 600° C. to 800° C. It was thus out of the question to heat a boiler with the residual gases, and, in order to produce the steam needed for the Horsfall furnaces, a separate portable engine had to be employed.

Very complete analyses have been made of the refuse from all quarters of the town and the rubbish was sorted into fifteen categories. Laboratory experiments were conducted with the ashes, the chimney gases and the cinders in the ashpit; these last still contained organic matter, indicating that the combustion in the furnaces was incomplete. As the outcome of the tests it was ascertained that each cell or chamber was capable of treating 2·79 tons of rubbish in twenty-four hours, which required from 6 per cent. to 7 per cent. of added fuel, and produced 26 per cent. of slag, and 27 per cent. of ashes—a total residue of about 53 per cent.; the corresponding figures in England being 6 tons to 7 tons per cell, with a residue of 33 per cent., no added fuel being necessary. Although the outcome of the experiments cannot so far be regarded as satisfactory, it has been decided to continue the tests until the autumn in order to ascertain whether the summer dust or refuse, which will not contain the ashes from the stoves, is more readily consumed than that in the winter time. Some experiments will also be made in sifting the refuse, as it has been found that the coarser portions burn more freely, though on sanitary grounds a separation of this kind must be condemned as much organic matter is present in the finer particles which pass through the sieves. The cost of the experiments up to the present has been about £3,350, of which £2,400 was expended upon the buildings and plant.

G. R. R.

Acetylene, a new Illuminant. By M. Hempel.

(Gesundheits-Ingenieur, 1895, p. 159.)

Common coal-gas is well known to be a mixture of gases differing greatly in their nature and properties. The component gases have been divided into three groups in accordance with their influences upon the illuminating power of the mixture.

1. The light-giving constituents, mostly the heavy carburetted hydrogens, which have specific gravities approaching that of the atmosphere.

2. The diluents, among which are marsh-gas, hydrogen and carbonic oxide, which burn and are productive of a high temperature, but which do not possess illuminating properties.

3. The adulterants, which include chiefly the nitrogen and carbonic acid as non-combustible elements, and the ammonia, sulphur and cyanogen compounds.

These properties of the constituents of common coal-gas are so well understood that various means are adopted to eliminate the impurities or to enrich gases of low illuminating power by the introduction of heavy carburetted hydrogen gases. If it becomes possible to produce a gas consisting wholly of the constituents included under the first of these groups, an almost ideal product for illuminating purposes is obtained. Such a gas is acetylene, which has the formula C_2H_2 and the specific gravity of 0·91. The Author describes the process of Willson[1] for the manufacture of calcium carbide on a large scale, and explains the use of this substance for the preparation of acetylene. He also mentions a special apparatus in which the mixture of the calcium carbide with water, with a view to the use of the resultant gas as an illuminant, can conveniently be carried on. This consists of a cylindrical vessel furnished with a perforated tray to contain the lumps of calcium carbide. A second vessel, placed at a higher level communicating with the gas-producer by means of a pipe, furnishes the water-supply. The gas-producer is fitted with a delivery-tube, a water-level indicator, a pressure-gauge and an orifice for the introduction of the calcium carbide. On turning the tap of the water-supply, the water rises in the gas-producer until it reaches the level of the tray of carbide and a rapid evolution of the gas ensues. The gas is so pure that it may be at once passed into the gas-holder for use. Any particles of sulphur derived from the coal combine with the lime of the calcium carbide and are retained in the gas-producer. As soon as the tap on the gas-delivery tube is closed the pressure of the gas in the producer forces back the water until it sinks below the level of the tray and the formation of the gas ceases. The plant for the manufacture of acetylene is thus extremely simple and can be contained in very small compass. Numerous tables follow setting forth the illuminating value, the comparative heat and the most effective combinations of acetylene with other gases.

G. R. R.

Improvements in Permanent Way on the Prussian State Railways. By R. Goering.

(Organ für die Fortschritte des Eisenbahnwesens, 1895, pp. 36 and 51.)

The Author states that flat-bottomed rails on the Prussian State Railways are gradually being superseded by double-headed rails

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[1] Minutes of Proceedings Inst. C.E., vol. cxxi. p. 372.

with chairs, and that at the close of 1892 the total length of chair permanent way amounted to 348 miles. After discussing the advantages of chair permanent way over that with flat-bottomed rails, the Author points out the directions in which the former requires improvement, which are as follows:—

1. Some means to prevent the sliding of the rails.
2. A better fastening between the rail and chair.
3. An increase of the contact surfaces between the chair and spike.
4. An increase of the bearing surface of the chair on the sleeper.

With a view to making the improvements the Author has designed types of chairs, keys, &c. On existing lines the new chairs are at present only being used at the joints for economical reasons. The bearing surface of the chair on the sleeper has been increased from 41 to 85 square inches, and the weight from 17·63 to 50·7 lbs. The bearing surface of the rail has also been increased from 2·95 to 5·71 inches, and three spike holes are provided in place of two. The outer fish-plates overlap the chair, and are keyed in with a timber key, two of the four bolts being countersunk to allow a smooth surface for the key. Dried, pressed, and impregnated oaken keys have been used, 8½ inches long by 2⅛ inches extreme width, costing 2½*d.* each, but the Author has found that the advantages of this key over those generally used are not such as to warrant the high extra cost, the ordinary keys being formed out of old oaken sleepers at a cost of 0·36*d.* each.

The spikes are 7¼ inches long, with a diameter of 0·63 inch, widening to 0·79 inch for the portion in contact with the chair. For one-tenth of the length a play of 0·16 inch has been left between the chair-plate and the head of the spike to allow for the vertical motion of the chairs on the sleepers at the joints. On the old permanent way eight sleepers were used for a rail 24·70 feet long, on the new nine sleepers are used, the end sleepers being 0·94 foot from their centres to the rail end, the intermediate sleepers being 2·82 feet apart centre to centre. The outside fish-plates are 32·76 inches long, and weigh 33 lbs. each, the inner ones are 19·13 inches long and weigh 20 lbs. each.

A further trial is being made on the new Brunswick and Meine line in the use of the heavier chairs entirely, and of steel keys in place of wooden ones. The object of the latter is to do away with the disadvantages attendant upon the drying and consequent slackening of wooden keys, and also to maintain as far as possible a fixed position of the rail. The trial length is 328 yards long, and is purposely laid in a most unfavourable position, being on a curve of 20 chains radius, and at the foot of a down gradient of 1 in 120 in close proximity to a station, over which the trains run with the brakes on at a speed of 25 miles an hour. The keys are in form somewhat similar to a channel-bar, with the flanges shaped to fit the inclinations of the web of the rail and jaw of the chair respectively. The top width of the key from outside to outside of flanges is 4·92 inches, the thickness of the flanges is $\frac{13}{32}$ inch,

and that of the web $\frac{15}{32}$ inch. The length of the key is 4·72 inches, the width of the jaw of the chain is 3·23 inches, and the key is widened out for $\frac{3}{4}$ inch on each side of the chair, thus maintaining a fixed position longitudinally. The web of the key has an inclination of 1 to 1·95 to the horizontal, the chief circumstance determining this being the fact that as the keys cannot be driven to their permanent position owing to their extra width at each end, they must be so shaped that they can be laid in their position. The cross section is designed with the object of having as much bearing surface as possible on the rail and chair with the smallest weight; the flanges have 1·57 inch bearing surface, and the weight of a joint key is 3·66 lbs. and of an intermediate key 4·54 lbs. The key is fastened to the chair by means of a screwbolt, 1 inch diameter, with a tee-head which fits into a recess in the chair, and the Author states that it is to be noted that this bolt is only subjected to tensile strains in the direction of its axis, and is not subjected to shearing strains. At the rail-joints where one fish-plate overlaps the chairs on each side of the joint, the width of the key is reduced to 4 inches. It has been found that when the nuts have been taken off the screws, it has been necessary to use a crowbar before the keys could be loosened and withdrawn. The steel keys are fixed on the inside of the rail, the Author being of opinion that there is no advantage whatever for the usual custom of keying on the outside being followed in this case, and, in addition, the inspection is very much simplified. On this test-length the keys have been made of cast steel in order to avoid the cost of new rollers, but if the experiment should prove successful, and up to the present it has given every satisfaction, the keys will be made of rolled steel and a certain amount of elasticity will enter into play. Under a rail 24·70 feet in length, there are eight sleepers, the centres of the end sleepers being 0·94 foot from the rail ends, the intermediate sleepers being spaced 3·28 feet centre to centre.

With regard to the costs of the new types of permanent way material, the Author gives the following:—

	s.	*d.*	
Chairs, manufactured from 80 per cent. of old chairs broken up and 20 per cent. best pig iron	0	9	each.
Chairs, manufactured entirely from best pig iron . .	1	11	,,
Keys, of oak, dried, pressed and impregnated . . .	0	2½	,,
,, of steel, at the joint chairs	0	11	,,
,, at the intermediate chairs	1	1½	,,
Bolts for steel keys	0	2¼	,,
Fish-plates, with bolts and washers	3	0¾	the pair.

The prices of the steel keys are the actual costs of the small quantities required for the test length, but the Author states that in manufacturing a large quantity the prices would be reduced to 2⅛*d.* and 2½*d.* respectively, and the price of the bolt to 1¼*d.*

The Author estimates the cost per lineal yard of this permanent way (excluding sleepers and ballast), with rails weighing 82½ lbs. per yard, at 18*s.* 3*d.*; and of permanent way with flat-bottomed

rails of the same weight at 14*s.* 8*d.*, or £2,414 and £2,092 per mile respectively with sleepers and ballast.

Two plates accompany the Paper, giving full details of the permanent-way materials described.

J. A. T.

The New Railway Stations in Dresden. By Otto Klette.

(Der Civilingenieur, 1895, p. 113.)

Between 1837 and 1875 six different terminal stations have been built in Dresden; the corresponding railway lines having been, from time to time, acquired by the State, the last purchase being in 1888. Designs for the concentration of the traffic into one central railway station were then put in hand. The Author traces the growth of the population and of the passenger-traffic during the period in question. At the new passenger station, the middle portion forms a double terminal station in which the rails are at the level of the surrounding streets; on both sides are through-lines of rails, 14·8 feet higher than the middle rails. This is the first example, to the Author's knowledge, in which a railway station has been arranged on this system.

The goods-traffic has been concentrated in one large goods station. The shunting and marshalling of the wagons is done by gravity; two sets of "gridirons," with eight and four lines of rails respectively, being used. The marshalling station is designed for handling 4,000 wagons daily.

The new stations—passenger, goods, mineral, &c.—will cover a total area of 560 acres, and will contain more than 100 miles of rails. The cost is estimated at £2,700,000. The actual cost will be somewhat greater, since the Corporation of Dresden has taken over some of the work not included in the above estimate.

The execution of the work must not interfere with the traffic; a period of ten years will therefore probably be necessary. The work was begun in 1890, with the building of the marshalling station. A considerable portion of the passenger station is expected to be ready in the summer of 1895.

The Paper is accompanied by seven sheets of plans.

A. S.

Five-axled, Eight-wheel-coupled Compound Goods Locomotives on the Prussian State Railways. By — Von Borries.

(Organ für die Fortschritte des Eisenbahnwesens, 1895, p. 3.)

To carry the increasing goods traffic on some of the Prussian State Railways—many of which have steep gradients and curves of small radius—five-axled, eight-wheel-coupled compound goods

locomotives have been constructed, with a view to diminishing the number of trains and to lower the carrying cost. In this type, in order to ensure smooth travelling and steadiness on curves at a speed of 28 miles an hour, a leading axle has been introduced, which the Author states has not hitherto been adopted for goods engines in Europe, although it has for some time been used in American locomotives. The total distance from the face of the buffers to the coupling with the tender is 32·59 feet, distributed as follows:—

	Feet.
From face of buffers to centre of leading axle	4·98
„ centre of leading axle to centre of first driving axle . . .	7·22
„ „ first driving axle to centre of second driving axle .	4·59
„ „ second „ „ „ third „ „ .	4·43
„ „ third „ „ „ fourth „ „ .	4·43
„ „ fourth „ „ „ coupling with the tender	6·94
	32·59

The total weight in service is 56·39 tons, of which 6 tons are on the leading axle, this being equal to 0·1064[1] of the total load, whereas hitherto one-fifth has been considered the proper proportion to be given to this axle. The leading axle has 2·95 inches play on each side; in order to lessen the side pressure, the second coupled axle has 0·31 inch play on each side, so it thus guides itself on curves of more than 25 chains radius. The cylinders are inclined at 1 to 20. There are 235 boiler tubes of 1·97 inch exterior diameter and 13·45 feet in length. The second and third driving axles are provided with a steam-brake, because the tender alone does not always command the desired brake-power. The greatest tractive force that the locomotive can exert is 8·37 tons, equal to one-sixth of the loads on the driving-wheel axles; and in order to ensure an even and symmetrical travelling on inclines, and in case of necessity to increase the tractive force, the Author's alternate valves are provided.

The efficiency of the locomotive in horse-power, calculated according to the formula $W = 2 \cdot 4 + \frac{V^2}{1000}$, has been ascertained as follows:—

Speed . . miles an hour	9·94	12·43	15·91	18·64	23·61
Effect on the wheel circumference . horse-power	493	567	616	661	671

This effect is about 50 per cent. above that of the three-axled, six-wheel-coupled locomotives, which the Author ascribes partly

[1] $\frac{1}{9 \cdot 4}$ in original.

to compound working, and partly to the small driving-wheel diameter.

The main dimensions of the locomotive are as follows:—

Cylinder-diameters . .	20·87 inches. 29·53 „
Piston-stroke	24·80 „
Driving-wheel diameter .	4·10 feet.
Steam-pressure . . .	176 lbs. per square inch.
Heating-surface (inner) .	1,550 square feet.
Grate-area	24·54 „ „
Weight in service . . .	56·39 tons.
Load on driving-wheels .	50·39 „

The relations of the main dimensions to each other have proved so effective in service that no alterations are being made in the locomotives in course of construction.

The first locomotive of this type was put into service in 1893, on the Soest-Northeim line, the gradients on which are as follows: firstly, 43½ miles of alternate up and down gradients of 1 in 250, then an up gradient of 1 in 100 for 10½ miles, then 19½ miles of level and easy gradients, and finally an up gradient of 1 in 100 for 9¼ miles. The Author states that the new locomotive draws trains consisting of 150 axles, each axle load being from 8 to 9 tons, without any difficulty to the foot of the 1 in 100 gradient; then a six-wheel-coupled locomotive is added: the latter being added in preference to one of the new type, in order not to place a too severe strain on the couplings.

An elevation and section accompany the Paper.

J. A. T.

Mallet's Articulated Compound Locomotives with Four Cylinders.

By Ed. Sauvage.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, June, 1895, p. 627.)

A concise account of the 152 locomotives of this type is found here illustrated by twenty-nine figures of the various designs, together with indicator diagrams, and an enlarged view of the articulated steam-pipe. It is pointed out that sharp curves and steep gradients frequently exist together upon railways, and the progressive development of Mr. Mallet's locomotives, designed to deal economically with traffic upon such lines, is traced from their commencement on the small railways, built on the Decauville system, to the more recent heavy locomotives for the St. Gothard and other mountain railways, which had previously been worked by ordinary locomotives. In designing this type, Mr. Mallet adopted several principles which had been already well established. The double-bogie engines of Fairlie and of Meyer had already demon-

strated the suitability of that method for providing flexibility of wheel-base; and Mr. Mallet preferred to adopt the single boiler of Meyer to the double boiler of Fairlie, while he closely followed the latter in the arrangement of a pair of cylinders upon each of the trucks. Mr. Mallet having himself demonstrated the suitability of the compound principle for two-cylinder locomotives, took what has since proved to be a successful step, in applying this principle to the double-bogie locomotive. Each bogie is carried upon two- or three-coupled axles, and carries a pair of outside cylinders, one bogie carrying the pair of high-pressure and the other the pair of low-pressure cylinders. The drawings explain clearly the method of articulation, and the horizontal intermediate steam-pipe beneath the boiler is of sufficient length to minimise the movement in its articulated joint, which is placed as near the bogie-pivot as possible. The front end of this horizontal intermediate steam-pipe has a telescopic movement usually in the form of a stuffing-box; but in recent engines built by Maffei this movement is allowed for by means of a series of corrugated disks, 1 millimetre thick, forming portion of the steam-pipe. For starting purposes, a special valve admits steam from the boiler into the receiver or intermediate pipe, which is also fitted with a safety-valve. The system of articulated compound locomotives was first applied extensively in the railway within the grounds of the Paris Exhibition, in 1889, where six locomotives, working sixteen hours a day, ran 71,000 miles, and carried 6,000,000 of passengers in six months. Twenty engines have been built for service on Decauville railways, and thirty-seven others have been constructed for lines in various parts of Europe of less than 1 metre gauge. Forty-eight engines have been constructed to 1-metre gauge, and forty-eight to the standard gauge of 4 feet 8½ inches. Most of the engines carry their own supplies of fuel and water, but those on the Baden and the Prussian State railways are provided with tenders. The largest engines are those constructed for the St. Gothard railway. These are tank-engines and are carried upon two three-axle trucks. They weigh 85 tons when full, and pass round curves of 120 metres radius. Several examples of the performance of Mr. Mallet's engines are given, of which the following is an example:—On the metre gauge of the Corsican railway an articulated compound locomotive, weighing 33 tons, draws 50 tons at a speed of 21 to 22 miles per hour up continuous grades of 1 in 33, with occasional curves of 100 to 150 metres radius. The dimensions of the boiler are such that during this performance 5¼ HP. are developed for each square metre of heating-surface. On the Central Swiss railway, engines with four axles and weighing 60 tons have given such satisfaction in their five years of service that ten additional similar locomotives have now been ordered for goods service. Engines weighing nearly 25 tons in service have been placed upon the departmental railways in France. These have high-pressure cylinders, 9·8 inches diameter, and the ratio of high- to

low-cylinder capacity is 2·31. The boiler pressure is 170 lbs. per square inch. With these engines Mr. Fettu has found that the most advantageous ratio between the mean pressures on high- and low-pistons respectively is 3 to 1, and several diagrams which are illustrated show that this ratio is approximately attained in practice. Locomotives of this type have been constructed by ten different makers, and they are distributed over various countries. France has sixty-five, most of which are of narrow gauge. Germany has twenty-six, all of standard gauge; while Switzerland has twenty-five engines, some of metre and others of standard gauge. The report closes by congratulating Mr. Mallet on the successful practical solution of the difficult problem of designing a flexible locomotive which utilizes the whole of its weight for adhesion.

E. W.

Bork's Brick-lined Locomotive Fire-Boxes. By — Bork.

(Verhandlungen des Verein für Eisenbahnkunde, Berlin, 1893, p. 100; American Engineer, February, 1895.)

The above-named and other recent articles, which have appeared in several foreign journals, are founded mainly upon the same experiments, viz., those made by Mr. Bork, Eisenbahn-Direktor of the Prussian State Railways, upon a locomotive fitted with a brick-lined fire-box and constructed at the chief workshops of Tempelhof, near Berlin. As long ago as the year 1879 the engineers of the Hungarian State Railways experimented upon three locomotives, in which the copper fire-boxes had been removed, the boiler-barrels closed with a tube-plate and the fire-box shells lined, in one case with fire-clay, leaving an air-space between the clay and the shell, in a second case with this air-space filled with slag-wood, and in the third case with fire-bricks built up throughout the box. It has been recorded[1] that the results obtained from some months' working with these fire-boxes were in some respects satisfactory, for the altered boilers made steam well, and the efficiency of the tubes was increased by their being exposed to a higher temperature than those in ordinary boilers, and the temperature of the outside surface of the fire-box shell was also cooler with the experimental boilers.

Some experiments were also made on the Swiss State Railways, but no conclusive result seems to have been reached, and the matter appears to have been left alone for more than ten years, when the Author communicated the results of his experiments with descriptions and illustrations in May, 1893. He begins by pointing out how few and insignificant have been the changes which have taken place in the locomotive boiler, in spite of its

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[1] Minutes of Proceedings Inst. C.E., vol. lix. p. 343.

great defects, since the first days of railways. The great number of stay-bolts and the little understood strains upon the ordinary fire-box are the cause of raising its cost of upkeep to from 20 per cent. to 25 per cent. of the total upkeep of the locomotive, and a proportionately long time is occupied in the repairs. The greatest number of boiler-explosions occur either in the fire-box or fire-box casing, and the fire-box must be looked upon as the most dangerous part of a boiler. The Author's chief experiment consisted in taking out the copper fire-box from a locomotive boiler, stopping the rear end of the barrel with a tube-plate, placing a cylindrical vessel about 2 feet diameter and 5 feet 6 inches long, containing water- and steam-space and united to this tube-plate by a cylindrical neck 13½ inches in diameter, in the upper part of the fire-box shell, and lining the remainder of the shell with fire-brick. The fire-bricks first used melted with the intense heat, running down the front and side walls, clinkering the fire and stopping up the grate-bars. They were afterwards made from specially refractory material, composed of burned slate and a plastic clay, containing a small amount of silicate to withstand a working temperature of 2,500° – 2,700° F. These bricks rested upon a channel-bar, taking the place of the old foundation ring, and were also supported by a firm conical iron ring at the fire-door. The bricks were about 4 inches thick, and frequent air-spaces, 2 inches wide, separated the main brick wall from the shell. The fire- or inward-side of the front wall was in the same plane with the tube-plate. A brick arch, about half the length of the fire-box, was provided, and the roof of the fire-chamber was arched just clear of the upper tubes and rested against the before-named cylindrical extension of the barrel, being secured to it by two angle-bars. The brick lining thus constructed was found to give about 12,500 miles of service. The length of the tubes was 13 feet 1½ inch, and the total heating-surface of this goods-engine boiler as altered was 14½ per cent. less than that of the original engine. The grate-bars were of the rocking type worked from the foot-plate. Owing to the intensity of the heat impinging upon the tube-plate and tube-ends, a diaphragm was fixed in the lower part of the barrel near the tube-plate, and inclined backwards towards it, to guide the upward current of water against the hot surfaces and keep them cool, thus overcoming a difficulty which had previously been experienced on the Hungarian State Railways. A hinged diaphragm plate was placed in the smoke-box, and after numerous experiments with a mercury thermometer, to ascertain the temperature of gases emerging from each tube, this diaphragm was located to obtain an almost uniform temperature opposite all parts of the smoke-box tube-plate.

A series of tests and careful measurements was made with the locomotive in service, using a dynamometer, speed-recorder and other instruments. The evaporation of water and the temperature, not only of the smoke-box gases but also that within the fire-box, were observed, the latter being taken behind the brick arch by

means of superimposed metal plates. Numerous samples of the burnt gases were obtained from the front of the smoke-box tube-plate under normal conditions of the fire, with the door closed and about 2 inches of water vacuum in the smoke-box. These gases were analysed for CO_2. The radiation of heat from the fire-box shell was ascertained on both the brick-lined and ordinary boxes by burying the bulb of a thermometer in contact with the plates beneath the clothing. This was done on all four sides of the boxes.

The locomotive was employed in hauling trains in a variety of goods service, with runs up to 80 miles in length, and was found to steam remarkably freely. On the maximum grades of 1 in 200 the smoke-box vacuum rarely rose above 2 inches of water. The principal results obtained from the foregoing tests are described in detail and may be summarised as follows:—In hauling trains the boiler having the brick-lined fire-box, although possessing 17 per cent. less heating-surface than the original boiler, proved at least of equal value. With speeds of 15·6 to 18·7 miles per hour, and with steam cutting off at from one-third to one-quarter of the stroke, and a vacuum of 2·4 inches of water in the smoke-box the engine with the new design of box exerted 450 HP., while under similar circumstances the engine with the ordinary boiler had exerted only 420 HP. The load hauled was also greater, but the maintenance of steam-pressure and water-level in the new boiler was attended with difficulty. The economy in the consumption of coal was shown by the premium allowances to reach from 10 per cent. to 25 per cent. The chemical analyses of the normal smoke-box gases showed 12 per cent. of CO_2, 6 per cent. of oxygen, and 82 per cent. of nitrogen, from which it is calculated that 71 per cent. more air was admitted to the fire than that which would be sufficient for the complete combustion of the fuel. This is more favourable than the case of the ordinary goods engine, which requires 2·3 times the amount of air necessary for complete combustion. From these data and the temperature of the smoke-box gases, which in both engines was about 525° F., calculations of the heat-units are entered into, and the conclusion is drawn that the walled fire-box secures an economy of 8 per cent. in the utilization of heat over the ordinary fire-box. The amount of radiation from the exterior of the fire-boxes was carefully calculated from the various observed temperatures of their surfaces, which in the new box were about 200° F. This radiation was found to vary very little in the two classes of fire-boxes, and to be insignificant in amount. Further calculations are made to prove that 62 lbs. of coal are required to heat up to the working temperature the fire-brick walls, which weigh about 1 ton. But this expenditure is also insignificant, for 330 lbs. of coal are required to heat up the ordinary boiler.

The economical advantages attending the use of this boiler depend on the greater intensity of heat within the brick-lined combustion-chamber, and the smaller quantity of cold air necessary

to complete the combustion of the fuel. Other advantages lie the diminished cost of construction, a reduced cost of fire-b maintenance amounting to about 29 per cent., and the possi adoption of a working steam-pressure as high as 235 lbs. per squ inch without increasing the thickness of the barrel-plates, further the safe use of steam at 300 lbs. per square inch in boilers. After about one year's continuous service the Aut concludes that the previous view of the necessity of the wa lined fire-box is quite unfounded, and that the principle of mak the heating-surface of a boiler directly proportional to the hauled has been shaken, since the loads taken by this locomot after losing the greater portion of its fire-box heating-sur were at least as great as those which can be taken by locomotive of ordinary design. He also points out that tractive power of a locomotive is regulated by the heat gene in a given time, and that the amount of heating-surface ne only sufficient to cool the products of combustion to a temper of 300° C. (572° F.).

After a further service of two years, although many experi locomotive engineers seem to be afraid of such a radical cha fire-box construction, the Author has recently designed a boiler, resembling the former in most particulars, but havin additional water-cylinders, about half the diameter and plac on each side of the former cylinder, and forming, together very small amount of brickwork, the roof of the fire-box brick walls are to be more securely fastened to the iron cas the addition of angle-bars riveted to the latter and built walls. The tube-plate is set rather further from the fi before, and the position of the diaphragm-plate in the slightly altered. Mr. Bork further states that for eighteen leaky tubes have never been observed, and that the brick fire-box have been renewed with very little trouble six tim economy in fuel observed at first has continued, and is small amount of air necessary for combustion; and the ten within the smoke-box is not higher than in the case of the water-lined fire-box.

American Locomotive Boilers.

(American Engineer, July, 1895, p. 311.)

The practice of building fire-boxes of mild steel proved during the last ten years. Greater care in of detail and in the selection of material has tended to life. The boiler here described is of the Belpaire ty number has been at work during the last two years pressure of 180 lbs. per square inch. The fire-box inches over the casing, some of the plates of

$\frac{5}{16}$ inch thick. The boiler has 31·18 square feet of grate area and 1,552 square feet of heating surface. The iron stays, which are screwed into the $\frac{5}{16}$-inch fire-box plates and riveted over, are not so closely pitched as in the usual English practice with copper stays and thicker copper plates, the spacing being about $4\frac{3}{4}$ inches on the sides and $5\frac{5}{16}$ inches on the fire-box crown sheet, which latter is $\frac{3}{8}$ inch thick. The corners of the upper portion of the box are bent to sharp curves to obtain as many tubes as possible, but a noteworthy deviation from former American practice is found in the large radii of the corners of the lower part of both inside and outside fire-boxes. Recent American locomotive-boiler practice is further illustrated on page 330 of this Journal, in the Report to the American Railway Master Mechanics Association, where several sketches of riveted joints, made by the Brooks Locomotive Works, are shown. One of these is a quintuple lap joint for a boiler barrel 68 inches in diameter. Most of the other sketches represent butt-joints in common use, with double-welt strips of varying proportions. The strongest of these is a longitudinal joint with an outside welt strip 9 inches wide and $\frac{7}{16}$ inch thick, and an inside welt strip 24 inches wide and $\frac{3}{8}$ inch thick, the latter being held to the barrel of the boiler by ten rows of rivets. This is used for boilers of exceptional diameter only.

E. W.

On some Desirable Modifications in the Types and Essential Working Parts of Tramway Engines. By P. Amoretti.

(Excerpt Minutes of Proceedings of General Meeting of Italian Tramways Association, Milan, 1894, p. 63.)

In a recent Paper [1] the Author gave a general description of the construction and equipment of the steam tramways in the north of Italy, and in the Minutes of Proceedings of the last General Meeting of the Italian Tramways Association at Milan, he has been enabled to present further particulars of the types of locomotives employed, with the view of more detailed consideration of such improvements or modifications as appear from experience to be advisable with regard to the conditions of construction and the various requirements of working.

With the development of traffic, heavier engines have been continually in demand, frequently without sufficient regard to the economical production of steam; and, speaking generally, industrial and financial exigencies have not always been found in sufficient accord with theoretical data, or with the requirements of technical experience.

In the limits of the present Paper it is not possible to do more

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[1] Minutes of Proceedings Inst. C.E., vol. cxix. p. 344.

than consider general principles and their bearings on practicable progress, leaving the working-out of details to be dealt with later.

Commencing with the boiler, three points may be noted for special consideration, viz., (1) production of heat, *i.e.*, combustion; (2) vaporization; (3) construction. In most existing tramway locomotives the combustion is somewhat imperfect, and the grate-area insufficient. With increased power of the locomotive the grate-area is frequently not enlarged, consequently the combustion in the earlier types is often better than in those of later date. In the Henschel type the proportion of grate-area to heating-surface varies from about 1 : 30 to 1 : 40, in the smaller and larger engines respectively, while in the Krauss type the corresponding and respective proportions vary from 1 : 35 to 1 : 66. The exhaust occurring at comparatively high pressure, the draught is powerful, and a considerable quantity of fuel can be burnt on a small grate-area, but with the drawback that it is necessary to keep it deeply banked. The air traversing this rapidly occasions a tumultuous combustion which is far from economical, much of the fuel being dropped into the ashbox, and a still larger part being blown out without being burnt, while the smoke-box is quickly choked up with coke-dust. The use of polygonal bars insures a more free circulation of air, and it is generally admitted that better combustion is obtained on wide than on narrow bars.

If the grate be enlarged a larger fire-box is required, securing a better mixing of the gaseous products of combustion with the air. If the fire-box is too small, bad combustion ensues, as the flames are extinguished at the tube-outlets, and useful gases escape unconsumed. It is, however, a matter of some difficulty to enlarge the fire-box on existing engines, on account of the space available between the frames, which prevents any additional width being given, while if made longer the wheel-base has to be lengthened. There is not, generally speaking, sufficient space for a deflecting diaphragm, and practically the only method of improving the combustion in existing locomotives is the introduction of air above the grate. The Author has tried this plan with great success, and proposes to adopt it more extensively. Of course, in new engines proper provision should be made for increased dimensions, both of grate and of fire-box.

While it may be affirmed with certainty that an increase of heating-surface is very desirable, it is apparently immaterial if the increase be made in the fire-box surface or in that of the tubes, so that the gross area is sufficient. In tramway engines it is generally difficult to greatly augment the indirectly-heated surface, so that the increase has to be effected on the direct surface. The tubes should not be too short; it is better to reduce the number, increase diameter, which should not be less than 1·5 to 1·58 inch, and give greater length, which conduces to more steady evaporation, and therefore gives drier steam. This construction also reduces the cost of maintenance. In good railway-

locomotives the amount of evaporation is about 8 lbs. to 9 lbs. of water per 1 lb. of coal; but there does not appear to be any satisfactory general result known in respect of tramway engines.

The Author thinks it very desirable to lag the boiler with some efficient non-conducting material between the shell and the outer casing.

In regard to practical construction the chief grievance in connection with Italian practice is the low limit allowed for tensile strength and working-pressure. The maximum stress is not permitted to exceed $2\frac{1}{2}$ tons per square inch, although soft steel plates are now obtainable, having an ultimate tensile strength of 25 tons per square inch. The working-pressure is limited to 176 lbs. per square inch, with the further obligation of annual reductions in this limit,[1] while in railway work the normal pressure is frequently allowed at from 206 lbs. to 220 lbs. per square inch. Boiler shells have, therefore, to be constructed much heavier than is really necessary, and there should be no objection to allowing the use of soft steel at a working strain of 3·175 tons per square inch.

The smoke-box is generally made too small, and is readily choked up. There is no impediment to the bottom of the smoke-box being lower than the underside of the boiler-shell.

Next, with regard to the utilization of steam, *i.e.*, to the motors, it is very desirable that the compound type should be generally adopted. The mechanism becomes, of course, more complicated, and economy of maintenance is always easier of attainment with simplicity in the working parts, but very great advantages are secured by compound working, not the least of which is the saving of from 15 per cent. to 20 per cent. in fuel. In existing engines no alteration can, naturally, be made; but in the future—especially if the working-pressure is allowed to be increased—the system should certainly be adopted. The two-cylinder type is the simplest and most economical arrangement, the proportionate volumes being 1 : 2 or $2\frac{1}{2}$, the diameter varying from 7 inches to 11 inches for the high-pressure cylinder, and from $11\frac{3}{4}$ inches to $17\frac{3}{4}$ inches for the low-pressure cylinder.

Up to the present time the locomotives in use are almost exclusively of two-axle type. A few have three axles, and in one case (Bari-Barletta) a four-axle engine is employed. The number must necessarily depend on the gradients and curves of the line, the solidity of the permanent way, and on the necessities of the traffic. For ordinary work the two-axle type is the best that can be adopted, but if it is necessary to adopt a heavier type of engine than the rail could economically sustain with the weight on two axles, it will, of course, be essential to increase the number. Similarly if, as previously recommended, the boilers are to be lengthened, the wheel-base has to be correspondingly increased. The rigid wheel-base of present types—4 feet 7 inches

[1] Minutes of Proceedings Inst. C.E., vol. cxix. p. 352.

to 5 feet 3 inches—is sufficient for engines up to 12 or 13 tons; but for heavier types and longer boilers this dimension must be increased to 6 feet or 6 feet 6 inches. The latter is a practicable length for curves of not less than 2 chains radius; but it must be borne in mind that allowance has to be made for curves on crossings and sidings, the latter in particular being frequently in a less perfect condition of maintenance. A curve of 1¼ chain radius will be appreciably deformed by a three-axle locomotive with a rigid wheel-base exceeding 5 feet 3 inches. On permanent way of the present normal type, in order that the stress should not exceed 4½ tons or 5 tons per square inch, the load per axle must not exceed 6½ tons, *i.e.*, for a three-axle engine a total load of 19½ or, say, 20 tons. The average weight appears to be about 18 tons. In Belgium, for instance, out of 208 tramway engines, 23 weigh under 18 tons, against 185 at 18 tons, with a very small number exceeding that weight.

In respect of the preference to be given to external or internal motion, most existing engines are fitted with the latter, which is more effectively protected from dust and is less conducive to swaying or rolling. On the other hand, external motion enables the centre of gravity to be lowered, facilitates the lengthening of the boiler, and is very convenient in many respects for the arrangement of the tender.

Several good types of brake are in use. Screw-brakes operate in a satisfactory manner, and the proposal to introduce the systematic adoption of steam-brakes is to be distinctly approved. On lines with long and steep gradients it is always advisable to have two brakes, acting independently of each other.

The Author, in conclusion, summarises the points in which modification or improvement is to be desired or sought for in the existing types of engines as follows:—

(1) Increased dimensions of fire-box.

(2) Longer boiler.

(3) The use of soft-steel plates for boilers, with increase of the limit of working strain to 3·175 tons per square inch, and working-pressure at from 206 lbs. to 220 lbs. per square inch.

(4) Adoption of the compound system.

(5) Increase of wheel-base, and, if necessary, increase in the number of axles.

(6) Adoption of steam-brake, in addition to other brake.

The Paper is accompanied by a tabular schedule of replies from the various Italian tramway companies in reference to details of the locomotives at present in use on the several lines, giving full statistics and dimensions of the same.

P. W. B.

Report on an Explosion of a Wood-Steamer.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1895, p. 140.)

The exploded vessel lay with two others in the basement of a two-storied building in Speele. The vessel was formed of a cylindrical shell, in two rings of mild steel, 0·6 inch thick, with dished end-plates 0·72 inch thick. The length of the cylindrical shell was 9 feet 6 inches, the diameter 5 feet 8 inches. Manholes for filling or emptying the vessel were placed on the front end-plate and on the top of the back ring of the shell. The circumferential seams were single lap-riveted; the longitudinal seams double lap-riveted.

To protect the inner surface of the plates against acids liberated by the steaming of the wood, a lining of cement, 4 inches thick, was inserted.

The exploded vessel was supplied in 1892. During a first trial considerable leakage occurred at the joint of the manhole-ring to the shell-plate, due to the fact that the radii of the two surfaces did not agree. The maker put this right, and in August, 1893, the vessel stood a proof-test satisfactorily. The vessel was used for steaming deal, in pieces about 20 inches long and 3 inches to 12 inches diameter, for a period of from ten to twelve hours under a pressure of 5 or 6 atmospheres. The steam was supplied from two water-tube boilers, working at a pressure of 8 atmospheres.

The vessel was considerably damaged by the explosion, a longitudinal rent being made along the whole length of the shell, and both end-plates were torn off from the cylindrical shell over a distance of two-thirds the circumference. None of the lines of fracture pass through rivet-holes.

Immediately after the explosion the safety-valves were tested and found to be in proper working order; the explosion, therefore, could not have been due to over-pressure. Specimens were cut from the plates after explosion and tested, the results being fairly satisfactory. A portion of the plate has been sent to the Commission on Testing of Old Boiler-Plates.

The Authors discuss various theories, but regret that, in spite of all their trouble, they have not been able to discover the cause of the explosion. A. S.

Boiler Explosion in Stassfurt. By C. Oehlrich.

(Mittheilungen aus der Praxis des Dampfkessel und Dampfmaschinen-Betriebes, 1895, p. 162.)

The Author gives an account of an explosion which took place in June, 1894, due to the collapse of furnaces in a boiler constructed on the Galloway system. After reviewing the evidence, he concludes that the explosion was due simply to shortness of water. A. S.

The Laval Steam-Turbine. By E. J. Brunswick.

(L'Électricien, vol. ix. p. 115.)

The Author, in an article on a portable search-light apparatus, describes the Laval turbine as the lightest steam-generator that can be employed for military field purposes where small weight is of great importance. The Author considers that the Brotherhood engines and the Parsons steam-turbine which have hitherto been used for this purpose do not meet all the requirements of the case, *i.e.*, light weights to facilitate transport and at the same time good efficiency. He describes the principle of the Laval steam-turbine as similar to that of the Pelton water-wheel. Instead of the power being obtained from steam expanding against a piston in a closed cylinder, the kinetic energy of the steam after escape from an orifice is utilized. The steam impinges on the vanes of a wheel revolving at the exceedingly high velocity of from 25,000 to 30,000 revolutions per minute. With careful geometrical design a theoretic efficiency of 87 per cent. is easily obtained, while in practice the commercial efficiency is stated to vary from 45 per cent. in the small sizes up to as high as 60 per cent. in the larger turbines.

The turbines consist of two essential parts, the wheel, and the casting containing the steam-passages and escape-orifices. These are so designed that although the steam enters them at the pressure of the boiler, by the time it reaches the exit opening adjoining the wheel the pressure is only that of the atmosphere. In fact, the potential energy of the steam has been all converted into kinetic energy in the same way as in many hydraulic turbines.

As the velocity of the steam on leaving the orifices is excessively high, 2,560 feet per second for 85 lbs. pressure, the actual period of contact between it and the revolving vanes is exceedingly small. It follows that where the circumferential dimensions of the disk and the size of the diverting orifices permit, it is possible to augment the power of the turbine by increasing the number of vanes. Owing to this the consumption of steam per HP. remains practically constant at all loads as the variation of power is effected by regulating the number of escape-orifices in use. The consumption of steam for turbines of 5, 10 and 15 B.HP. is stated to be about 44 lbs. per HP. with atmospheric exhaust, and with a boiler-pressure of 85 lbs.

The Author then proceeds to describe the essential mechanical details of construction. At the excessively high speeds of these turbines, *i.e.*, 30,000 revolutions per minute for the 5-HP. size, and 24,000 revolutions for the 10 and 15 HP., the centrifugal forces are enormous. The inventor has shown great ingenuity in overcoming slight want of balance by certain gyrostatic propensities of the revolving parts. The speed of the principal axis is reduced in the ratio of 10 to 1 by screw-gearing and hence the

dynamos need only be constructed for more moderate speed of 2,400 to 3,000 revolutions.

The weights of the turbines complete are as follows:—

Effective Power of Turbine.	Speed of Turbine.	Speed of Dynamo.	Weight of Turbine only.
HP.	Revolutions per Minute.	Revolutions per Minute.	Lbs.
5	30,000	3,000	286
10	24,000	2,400	440
15	24,000	2,400	517

R. W. W.

Test of a Pumping-Engine at Karlsruhe. By E. Brauer.

(Mittheilungen aus der Praxis des Dampfkessel und Dampfmaschinen-Betriebes, 1895, p. 225.)

The Maschinenbau-Gesellschaft Karlsruhe built a new pumping installation for the Karlsruhe Water Works; the following is an account of the trials made December 18th to 22nd, 1894:—

Test of the Pumps.—The pumps were specified to run at 30 revolutions per minute, and deliver 420 cubic feet of water against a head of 170 feet; further, the number of revolutions may be increased to 37½ per minute without the volumetric efficiency being less than 0·85. During the first trial, lasting half an hour, the pumps made 30·7 revolutions per minute, and had a volumetric efficiency of 0·91.

Test of the Engine.—The engine is compound-condensing, cylinder diameters 24 inches and 35·2 inches respectively, stroke 44 inches. Three engine-tests were made of durations 400, 110, and 105 minutes respectively; the indicated horse-powers being 153, 180, and 172 respectively, the effective horse-powers (measured by the quantity of water pumped) 131, 146, and 152. The steam-consumptions per effective horse-power per hour were 19·7, 20·0, and 19·1 respectively.

Test of the Boilers.—The boilers are two in number, of the Lancashire type, each with two feed-heaters. The diameter of the shell is 76 inches, length 25 feet, diameter of the flues 29 inches. In each flue are three cross-tubes. During the tests only one boiler was used. The boiler-test lasted seven and a half hours, an efficiency of 0·837 being obtained.

Professor Brauer remarks that the regularity of the working of the pumps leaves nothing to be desired, and that the whole installation answers its purpose admirably.

A. S.

Gas- and Petroleum-Engines at the Antwerp Exhibition of 1894.

By G. Lambotte.

(Revue Universelle des Mines, vol. xxx., May, 1895, p. 128.)

The Author commences this article with a brief explanation of the general theory of these engines. The gas- and petroleum-engines examined were exhibited by twenty-one houses, Belgium contributing fifteen, England fifteen, Germany thirty, and France six. Each pattern of engine is described in detail, and, where conspicuous, their defects and advantages are pointed out. A general comparison of the various types employed is also given. The Author commends the exhibits of England, where the horizontal type is affected. The engines are of simple construction, solid, well balanced, and elegant, without useless wealth of detail. The German engines of large power, and especially the petroleum-engines, are vertical; they affect an excessive amount of detail, to which, in a great measure, practical considerations appear to be sacrificed.

On account of the formidable competition of England and Germany it has been found necessary to construct the Belgian motors as simply as possible, whilst leaving nothing to be desired in their efficiency; and this, the Author claims, has been successfully accomplished. The number of gas- and petroleum-engines employed in Belgium is very limited, and the only reason for this, in a country where fuel is so cheap, appears to be the prejudice of the small manufacturer. At the beginning of 1894 there were in Belgium only 1,069 gas-motors, representing 3,490 HP., whilst in England at the same period the number amounted to 40,000. In France, where gas is costly, the number of engines in 1889 compared with that of Belgium, for the same population, as 3 to 2; and engines of large power have hardly been introduced into the latter country owing to the scarcity of anthracite coal.

The petroleum-motor, which was barely represented at Paris in 1889, occupied a prominent place at the Antwerp Exhibition; and the Author holds that, considering the improvements of which the gas-engine is undoubtedly capable, it seems reasonable to expect yet greater developments from the more complex and, in many respects, more advantageous petroleum-engine of modern birth. A comparison is then drawn between steam-, gas- and petroleum-motors with regard to economical and other advantages.

Based on conditions prevailing in Brussels, and taking into account interest on first cost, maintenance and working expenses, the results shown in the following table are arrived at, showing that up to 10 HP. the petroleum-motor is the most economical; that at that power the cost of all is about the same; and that

above it steam is the cheapest for continuous work of any duration:—

Power.	Cost in Pence per I.HP. per Hour.		
	Gas.	Petroleum.	Steam.
2 I.HP. . .	2·93	1·74	2·91
10 „ . .	1·06	0·97	1·06
50 „ . .	0·49[1]	..	0·49

For 50 HP. the daily cost is the same for coke, gas and steam, but in the neighbourhood of anthracite mines the advantage lies with the gas-engine, which would only require 1·33 lbs. of anthracite per HP. per hour, whilst the steam-engine would consume 3·33 lbs. of coal.

The Paper also contains a comparison of the power developed per pound of coal in each class of engine, taking into account the by-products realised in the manufacture of the gas, and concludes with the remark that when the gas-engine shall have been perfected by improvements in the cycle and generator the solution of the problem of large power gas-motors may be expected; reference being then made to the 320 HP. engine at Pantin,[2] which consumes 50 per cent. less coal than a good steam-engine of the same power.

J. R. B.

Report on the Experimental Boring for Petroleum at Sukkur.

By T. H. D. La Touche, B.A.

(Records of the Geological Survey of India, 1895, p. 55.)

Reasons are given for the choice of the position of this boring, which was commenced in December, 1893, upon the advice of Dr. King, late Director of the Geological Survey of India. One of the chief of these reasons was its vicinity to the workshops of the North Western Railway, while it was also at a convenient distance within the area of outcrops of the nummulitic limestone, the base of which forms a well-defined horizon for comparative measurements in relation to sections or borings in other localities. The limestone was struck at a depth of 38 feet 6 inches, and an 8-inch casing was put down to this level through the superficial layers of alluvial sandy clay. The base of the limestone was reached at 140 feet from the surface, and the bore-hole then passed through beds of shaly blue clay down to 409 feet, where a thick bed of

[1] Generator gas. [2] Minutes of Proceedings Inst. C.E., vol. cxx. p. 420.

limestone was again entered. The bore-hole was lined with 6-inch casing down to 440 feet and $4\frac{5}{8}$-inch casing was then used. Ultimately the 6-inch casing was continued to a depth of 1,056 feet. About 940 feet of shales and clays of very uniform character were passed through beneath the limestone. Mr. Griesbach pointed out that these beds resemble in all respects those found below the nummulitic limestone in Baluchistan. As the boring so far has had no success, it becomes a question whether it should be continued, and reasons are given by the Author from certain indications obtained of the existence of oil at Rohri, about 8 miles distant, for carrying the bore-hole to a depth of not less than 1,600 feet.

G. R. R.

Crane driven by a Gas-engine. By C. JIMELS.

(Le Génie Civil, July 27, 1895, p. 197.)

This crane has been erected by the "Compagnie Parisienne d'Éclairage et de Chauffage par le gaz" on its coal wharf at Clichy. Safety and economy in handling were specially studied in its design.

The crane is fixed on the staging of the wharf, and the jib, which is pivoted to allow of slewing in either direction, has a radius of 24 feet 7 inches. The crane is designed to lift 1·18 ton of coal in a skip weighing 10 cwt. (or a gross load of 1·68 ton) to a height of 68 feet 9 inches, with a velocity of nearly 100 feet per minute. The motor, which runs continuously and in one direction only, is a two-cylinder gas-engine, the cylinders being 9 inches diameter and $15\frac{3}{4}$ inches stroke, developing $15\frac{3}{4}$ HP. at 140 revolutions per minute. The slewing motion is taken off the first motion shaft by means of bevel friction wheels, and the lifting by a grooved friction pulley. The brake is automatic, and must be held off. The load is lifted on two parts of a wire rope, which passes down the centre of the jib-pivot, and is guided on to the grooved winding-drum by two pulleys, one of which travels along a screw receiving motion from the drum. The jib is curved, formed of angles and bracing, and counterbalanced at the back by a weight of nearly 2 tons. All the machinery is covered in by a light housing, built right up to the edge of the quay. In the steam-cranes formerly used on this wharf both a signalman and oilman were required in addition to the driver, but with the gas-driven crane one attendant only is sufficient, being placed close to the edge of the wharf, so as to be able to see into the hold of the vessel that is being unloaded.

The article is accompanied by two pages of details, as well as a photographic view of the crane. No actual cost of working is, however, given.

R. B. M.

The Sinking of the Ladd Shafts. By G. S. Rice.

(Journal of the Illinois Mining Institute, 1895, p. 13.)

The Author describes in detail the sinking of a number of shafts at Ladd, Bureau County, Illinois. These shafts were sunk to a depth of 460 feet to work the third coal seam from the top, and considerable difficulty was encountered in the first 160 feet, which consisted of a drift deposit of clay, sand, and gravel interspersed with boulders sometimes of great size. In the first successful shaft the maximum amount of water raised was 620 gallons per minute, but this decreased in the second and third shaft, and the time required was much less. After various methods of shaft-sinking had been tried, it was found that the most satisfactory plan was to use a rectangular shoe supported from timbers at the surface and forced down by jacks bearing under the completed lining. In this way three of the original six attempts were finally successful, and all the shafts in which the shoe was used succeeded in reaching rock. The shoe, as finally developed, was used in sinking B shaft in the following manner:—A platform of 2-inch planks was laid on the surface, and across these 60-lb. steel rails were placed parallel to the sides of the shaft so as to form the foundation of four solid wooden triangles carrying the weight of the curbing. Each triangle was made of eight pieces of 12-inch square timber, the bottom one being 48 feet long, the next 4 feet shorter, and so on to the top one which was 20 feet long. On the triangles two 16-inch square timbers 20 feet in length rested, and through these passed the eight hanging steel rods that sustained the curbing. The whole formed an almost rigid structure that subsided as one mass. The support to the curbing was an iron lug placed under the screw coupling-piece at each joint of the 10-foot lengths in which the hanging rods were made and spiked to the cribbing. The shoe was 12 feet 8 inches by 17 feet 6 inches in inside dimensions. It was built of $\frac{3}{4}$-inch steel plates, the sides being 4 feet deep, of which the upper 16 inches was the shield holding the bottom of the curbing. The lower part of the shoe was divided into twelve compartments by three transverse and two longitudinal lines of braces. A shelf, 9 inches wide with a 2-inch ledge in front, ran round the inside of the shoe 12 inches from the bottom, so as to form the press-plate on which the jack-screws for forcing down the shoe were placed. The shoe was never forced down more than 10 inches at a time, so as to leave 6 inches at least of shield overlapping the cribbing. Its weight was 8 tons. The excavation and pumping proceeded, according to circumstances, with the usual appliances.

When there is water-bearing ground over 80 feet in thickness to be pierced, too soft for solid-ground systems of shaft-sinking and yet containing boulders which would militate against the use of any kind of drop-shaft, the method described by the Author appears

to be the only one, with the exception of the freezing process, that can successfully be used. The Author's description, which covers thirty-four pages, is illustrated by dimensioned drawings of the shoe, of the rod-couplings, of the solid wood triangles, and of the finished shafts.

B. H. B.

The Development of the Iron and Steel Manufacture as shown by recent Exhibitions in France. By J. Euverte.

(Mémoires et Compte rendu de la Société des Ingénieurs-civils, June, 1895, p. 781.)

The Author points out the great value of the records relating to the state of the iron and steel manufactures which have been furnished by the great French Exhibitions of the past, and desiring to give as exact and reliable an account as possible of the present state of the industry in France, he based his work on the results of the Exhibitions of 1889, in Paris, and of 1894, in Lyons. He admits that the progress realised in the course of the last ten years as shown by the Exhibitions of 1889 and 1894 is well known and appreciated at its true value, but believes that certain information recently furnished by manufacturers might serve to give a rational and satisfactory explanation of the cause of this remarkable progress. To show the enormous strides made by the industry, the Author gives a comprehensive description of the exhibits and a rapid summary of the facts established at the various Exhibitions held in France since 1855, specifying the most marked characteristics of each period.

In connection with the description of the displays of the 1889 and 1894 Exhibitions he gives the following Table, showing the total production of pig-iron for the world, taken from a Paper by Mr. Shroedter read in January, 1895, at the General Meeting of the German ironmasters.

Production of Pig-Iron (in Thousands of Tons).

——	1867	1878	1889	1893
France	1,239	1,508	1,734	2,032
Belgium	423	519	832	760
England	4,839	6,366	8,458	6,930
Germany	1,264	2,148	4,524	4,953
America	1,326	2,338	7,872	7,239
Other countries	934	1,419	2,609	4,875
	10,013 (*sic*)	14,298	26,027 (*sic*)	26,989 (*sic*)

Another Table, giving the output of iron and steel of different

countries in 1888, shows, that after a period of twenty years, the annual production had reached 10,000,000 tons.

Having pointed out the progress and improvements made in the manufacture of steel as shown by recent Exhibitions, the Author enquires whether there be not a cause for these, not generally appreciated. He attributes it to the method of scientific and experimental research applied to the manufactures in France, where, he maintains, the progress made has unquestionably been greater than elsewhere, and where processes invented by foreigners have met with greater success.

Since 1867 a large number of studies have been made on the chemical composition of iron and steel, and on the mechanical properties produced thereby. Many of the results have been published at the time of the various important Exhibitions held in France, and the Author appends to his article eleven Tables, comprising data which the exhibitors had no objection to publishing; and from a selection made of these the results are depicted graphically in order to show at a glance the different properties of the steels under study. An examination of the diagrams, supplemented by the information contained in the Tables, enables a number of interesting conclusions to be drawn.

During the first months of 1895 several manufacturers attempted the production of a steel possessing the following qualities:—

Limit of elasticity . . .	56,893 to 64,004 lbs. per square inch.
Breaking weight	113,786 „ 184,902 „ „ „ „
Elongation	30 per cent.

Although entire success has not been met with, some remarkable results were obtained as shown below:—

——		No. 1.	No. 2.	No. 3.	No. 4.
Limit of elasticity .	lbs. per sq. inch.	47,505	47,505	56,181	61,871
Resistance . . .	lbs. per sq. inch.	95,011	98,709	107,811	126,586
Elongation . . .	per cent.	46·0	47·5	49·8	35·6
Contraction . . .	per cent.	66·6	71·2	61·6	57·0

A study of the Tables given shows that there is no difficulty at the present day in producing a steel with the following qualities:—

Limit of elasticity . . .	56,893 to 64,004 lbs. per square inch.
Resistance	78,228 „ 85,339 „ „ „ „
Elongation	25 „ 22 per cent.
Contraction	55 „ 45 „

The Paper records some decidedly novel achievements which will lead to results that it appears possible to foresee to-day. Regarding the different chemical combinations made in steel, the Author thinks it certain that others exist which have not yet been

revealed by the manufacturers, and believes that further considerable progress is likely to result. Up to the present the attention of manufacturers has been confined to the mechanical properties and chemical composition of the metal; when it shall have been turned to the study of the molecular state the Author considers a great improvement in quality may be looked for, and maintains that this desideratum will undoubtedly be accelerated by the publication of the results of the experiments undertaken by the commission appointed in 1891 by the Minister for Works of France to experiment on materials of construction.

The Paper ends with particulars of an economical nature showing the benefits already derived and likely to be in the future from the march of progress.

The following Table shows the production and average price of pig-iron during certain intervals from 1853 to 1894:—

	Tons.	Price per Ton. £	s.
1853.	660,934	6	12
1867.	1,203,903	3	14
1878.	1,521,274	3	10
1893.	2,077,647	2	4

Other figures give the production of steel in 1878 at 269,181 tons, and in 1894 at 663,264 tons; this increase being mainly due to the use of the Siemens-Martin and the Thomas Gilchrist processes. The total saving in the manufacture of steel and iron in 1894 over 1853 is given as amounting to over £9,000,000.

The Author comments on the annual production of steel during the past years, and argues hopefully for an encouraging outlook for the future of the industry, both as regards output and profit.

J. R. B.

A New Method of Determining Carbon in Iron. By E. Volmer.

(Stahl und Eisen, vol. xv., 1895, p. 199.)

Mr. Peipers, an engineer at Remscheid, has introduced a method of determining carbon in steel which is similar in principle to the assay by touch in use for gold. A series of test-bars of known carbon contents, and varying from each other by about 0·2 per cent. between the limits 0·2 per cent. and 1·2 per cent., form the touch-needles, while the touchstone is represented by a slab of hard-biscuit porcelain. The bar is hammered and filed to a blunt conical point, which leaves a black mark when rubbed on the porcelain slab. The sample to be examined is rubbed upon the centre of the plate to form a patch of about the breadth and length of the finger, a similar one being made on either side of it with two of the bars whose composition is known. The chief point to be attended to is to make the patches uniform in depth of tint,

which can be readily done with a little practice. The marked slab is then immersed to about half its depth in a beaker containing a 12½ per cent. solution of copper-ammonium chloride in water, which dissolves away the iron from the immersed portions of the patches, leaving the carbon behind as a grey stain, whose intensity increases with the percentage proportion. Steel with about 1½ per cent. of carbon is nearly as dark after as before immersion, while that with 0·25 gives only a very pale shade when the iron is removed. If the metal were perfectly free from carbon the mark would be completely dissolved.

Numerous substances have been tried for streak plates, including agate, Arkansas stone, hard glass, and feldspar, but none of them have been found equal to unglazed porcelain. In its ordinary state, however, the latter is too rough to abrade the metal equally, so that it must be rubbed down with coarse emery-cloth to render the surface sufficiently uniform. The markings may be nearly completely removed by washing in water, but a more satisfactory method is to clean the slab by immersion for fifteen minutes in nitric or hydrochloric acid, which removes rust spots and stains, and restores the original white surface. The method is capable of indicating differences of 0·05 or 0·025 per cent. of carbon under favourable conditions. The cost of the apparatus is about £1 2*s*.

H. B.

On the Manufacture of Tool Steel in Styria and Lower Austria.

By A. Ledebur.

(Stahl und Eisen, vol. xv., 1895, p. 1.)

The principal seat of crucible-steel manufacture in the Austrian Alpine region is at Kapfenberg, about 3 miles from Brück in Styria, where several falls of water, together equal to about 530 HP., are obtained from the tributary streams of the Murz Valley, a nearly equal power in addition being utilized at several tributary works in the neighbourhood. The basis of the manufacture is the charcoal pig-iron of Eisenerz and Vordernberg smelted from the spathic ores of the Styrian Erzberg, which vary in composition between the following limits:—

—	Per Cent.	Per Cent.
Carbon	3·50	4·20
Silicon	0·11	0·24
Manganese	0·80	2·40
Phosphorus	0·03	0·07
Sulphur	..	0·02
Copper	..	0·005

This is converted into crude steels both by the open fire finery and the puddling furnace. In the former the old Styrian crude steel process is followed exactly in the same manner as described by Tunner (Percy's "Iron and Steel," p. 783). The bloom obtained being reheated in the same fire during the melting down of the pig-iron forming the next heat, and drawn under a tilt-hammer into bars about 1 inch square, which are chilled in water and broken. The loss on the weight of the pig-iron treated is from 12 per cent. to 14 per cent., and the consumption of charcoal, including waste by crushing, 1·6 to 1·7 hectolitre per 100 kilograms of steel (about 600 cubic feet per ton). The puddled steel made from the same pig-iron is converted into bars by rolling, which are hardened and broken for sorting in the same way as those from the open fire. Although the proportion of phosphorus is very similar in the steel obtained by either method, 0·010 per cent. to 0·019 per cent. in the open fire, and 0·018 per cent. to 0·022 per cent. in the puddling furnace, the former gives a product of a decidedly higher class when melted, and is therefore used alone for the highest qualities of tool steel, while from inferior marks it is mixed with the puddled metal. As the result of a long-continued series of experiments, the addition of mild steel, Bessemer, or open-hearth, to the crucible charges has been abandoned. Sometimes blister steel converted from wrought-iron made in the open fire is added, but curiously enough this is found to contain more phosphorus than the crude steel made from the same material.

The crucibles used for melting the steel are made of Styrian graphite, containing carbon 77·95 per cent., silica 13·04 per cent., alumina 6·12 per cent., ferric oxide 0·44 per cent., potash 0·43 per cent., water 1·95 per cent., mixed with clay in different proportions. For mild tempers with 0·3 per cent. to 0·4 per cent. of carbon, sufficient graphite is added to give crucibles with 25 per cent. of carbon, while for the harder qualities it is increased to about 45 per cent. The moulding is done in power-presses. After a slight superficial drying the crucibles are removed to the drying-room, a group of three chambers filled with racks of shelves, with a total surface of about 12,000 square feet, where they are slowly dried in a current of warm air from a cast-iron gill-pipe stove heated by a fire of lignite. The hot air enters the room at about mid-height, and the moisture-laden atmosphere is removed by an exhauster through a passage below the floor on the side opposite to the fire-place. When required for use the stove-dried crucibles filled with the charges to be melted are very gradually brought up to a bright red heat in a furnace somewhat similar to a gas melting hole or a soaking pit with accessory firing. They are then transferred to the melting furnaces, which are of reverberatory form, with Siemens gas-firing; gas from the producer placed below the floor-level and air coming from opposite directions, right and left, meet in the combustion-chamber at one end of the furnace, and the flame follows the longitudinal axis of the melting-hole, which has

a capacity of eighteen or twenty pots. Each furnace has its own gas-producer and chimney, the latter being about 18 inches square and 68 feet high. The fuel used is lignite slack of a very inferior quality, having a calorific power of 4,898 and an evaporative factor of 7·77 or only about half that of good coal. Two and a quarter tons are required to melt 1 ton of steel, which includes that necessary for the preliminary heating. The crucibles holding 66 lbs. are only used for one heat, being thrown aside after pouring to be broken up and ground for re-manufacture. The ingots are cast in moulds with fire-clay necks, which are varied in size with the hardness of the metal, so as to be able to get as great a length of the ingot sound as possible.

A curious fact has been observed that the ingots contain somewhat less phosphorus, 0·008 per cent. to 0·013 per cent., than the crude steel of the charge, a result that the Author considers may be due to the separation of a small quantity of forge slag entangled in the metal and which is removed in the melting. The ingots are reheated in gas-fire reverberatory furnaces and tilted down to bars by water- or steam-power hammers in the ordinary way, a portion of the production, together with Bessemer ingots from Carinthia, being, however, worked up at the rolling mills belonging to the same proprietors near Waidhofen in Lower Austria. The reheating of ingots and large blooms is done in a Siemens furnace with lignite gas, which deposits a considerable quantity of tar in the cooling siphon of the producer. This tar is utilized as fuel in the reheating furnace for the smaller sizes which has an ordinary grate fire, with a channel about 7 inches square along the face of the fire-bridge, which is kept full of tar by a supply-pipe from a cistern above. The flame from the fire carries the tar over as vapour which is burnt in the hearth of the furnace. A second tar-pit of the same kind is placed at the flue end to improve the heating-power of the spent flame which is used for raising steam before passing into the stack. This furnace has been so successful that another has since been erected.

In the classification of the bars made from Bessemer ingots a method is adopted which is described as follows:—The steel to be tested is forged to a flat (12 by 4 millimetres) bar 400 millimetres long, with one end drawn taper to a wedge about 70 millimetres long. The wedge end is placed in a charcoal fire and brought to a bright red heat, and then hardened by immersion in water at about 20°, where it is kept stationary until cold. The hardened part is then tested with a file, which will not touch the surface of a very high carbon steel, but with intermediate qualities it will just cut the base of the wedge, while the mildest kind can be filed nearly up to the point. To an experienced ear the "cry" or tone of the file on the hardened surface furnishes a very exact measure of the hardness. The hardened bar is then broken at different places with a hammer and examined for the indications afforded by the colour and grain of the fracture. The bar is then placed in a vice with the unhardened end projecting and bent gradually by

blows from a hammer until broken. The bend, measured by putting the fragments together and drawing the outline with a pencil, gives a good indication of the hardness, as with bars of similar temper the angle of the bend is tolerably constant. Softer kinds may be bent under the hammer to a loop, but it is in only the mildest ingot iron that the loop can be squeezed flat in the vice without breaking. As a consequence of long practice the workmen are able to recognise minute differences with these tests with extreme accuracy. The ingots received from the Bessemer Works are of four kinds, Nos. 4, 5, 6 and 7 of the Austrian scale, with carbon ranging from 0·15 to 0·75 per cent., and these are divided by the hardening test into twenty-four different classes of finished bars, each of which is distinguished by a particular mark.

H. B.

The Tin Deposits of Durango, Mexico. By W. A. Ingalls.

(Advance Proof, Transactions of the American Institute of Mining Engineers, March, 1895.)

It is uncertain when tin was first discovered in Mexico, but it is probable that the metal was known and worked by the Aztecs and kindred native races at the period of the Spanish Invasion. The first exact reference is, however, to be found in Humboldt's essay on New Spain, who gives the names of the localities producing tin ore at the date of his visit in 1803, and the list has been largely extended by subsequent travellers. There are records of mining at only a few of these places, the most important of these being Cacária and Potrillos in the State of Durango, and Teocaltiche in that of Jalisco.

Potrillos is situated on the western mountain district of Mexico, about 100 miles north of the city of Durango, and 170 miles north-west of Mazatlan on the Pacific. The general elevation of the valleys is between 6,500 and 7,000 feet, the mountains rising from 1,500 to 2,500 feet higher. The prevailing rocks are masses of igneous origin, rhyolite and rhyolite tuffs, which cover vast areas in northern and north-central Mexico. The rhyolite tuff is a greyish white soft rock very much decomposed, even at a depth of 150 feet from the surface, which crumbles rapidly when exposed to the air, but occasionally hard brittle masses of devitrified obsidian are found enclosed in it. The mass is traversed by joint planes, and faults coursing east and west with a southerly dip. The tin ore occurs in the fault fissures, which are usually very narrow, in aggregates of nuggets (called *guijilos* by the native miners), and occasionally in crystalline bands replacing the rock. In the first mode of occurrence, which is most common, there are all gradations from nests of pure mineral down to small particles disseminated in vein stuff assaying about 1 per cent. The ore that has been mined has generally averaged from 3 per

cent. to 10 per cent. of tin, and has been broken from breasts 3 feet to 4 feet wide. The pockets, which are never large, form a series or chain connected by thin strings of ore, having a general westerly dip of about 45 degrees. In the Candelaria mine, a section of which is given, the deposit is followed by a series of very irregular workings for about 160 feet on the slope, or about 100 feet below the surface. There are probably very many of these small deposits scattered over the country, which, although individually of insignificant value, have by the waste of the rock near the surface given rise to the stream-tin deposits upon which the reputed value of the locality as a tin-producing centre was founded. These alluvial workings, which were formerly productive, are now exhausted, and the drift deposits on the hill-sides are mostly too poor to pay for the expense of bringing water to them.

In the Cacária district the veins are irregular fissures in quartz porphyry filled with red clay with disseminated grains, scales and nuggets of very impure tin-stone associated with arsenate of lead, wolfram and molybdenum minerals. The average yield of the vein stuff is about 3·75 per cent. of black tin. The greatest depth explored in this district was 273 feet in the Diablo Mine.

A Table is given of ten analyses of Mexican tin ores made by the late Dr. Genth, half being from Potrillos and the remainder from Cacária. The former is fairly pure, containing 92 per cent. to 93 per cent. SnO_2, 4 per cent. to 6 per cent. Fe_2O_3, and 0·7 per cent. to 2·7 per cent. silver; but the latter is remarkable as containing arsenic in appreciable quantity up to a maximum of 10·34 per cent. of arsenic acid (As_2O_5). The Durango tin as shipped to the United States is free from wolfram, but sometimes contains antimony. Two analyses of parcels of about 25 tons total weight were of the following composition:—

Tin	92·6104	90·6047
Antimony . . .	7·3139	9·2850
Arsenic	trace	trace
Lead	0·0331	0·0555
Bismuth	0·0255	0·0276
Iron	0·0171	0·0270
	100·0000	100·0000

In no portion of the ore were independent antimony minerals recognisable by the eye, so that it was probably combined with the stannic oxide in the same way as arsenic is in that of Cacária. The Author has also found 6·83 per cent. of antimony in tin smelted in a native furnace at Canitas, where the conditions of occurrence of the mineral are similar to those of Durango.

H. B.

The Ducktown Ore Deposits. By Carl Heinrich.

(Advance Proof, Transactions of the American Institute of Mining Engineers, March, 1895.)

The Ducktown copper-mining region is situated in the south-east corner of the State of Tennessee, adjacent to the western boundary of North Carolina, while the southerly extension of the ore deposits carries them some distance over the northern boundary line of Georgia. The country forms part of the Appalachian mountain system, the rocks consisting chiefly of gneiss and mica schist, being sharply folded into curves whose axes strike about N. 25° E., or about the general direction of the main chain of mountains. The ore deposits occupy fissures which, according to the Author, are due to faulting, their principal constituent being magnetic pyrites with subordinate quantities of iron and copper pyrites, zinc-blende and galena. These form lenticular masses varying from 12 feet to 400 feet in thickness, which are very irregularly distributed over an area of about 6 miles by 3 miles. From the surface to a depth varying from 17 feet to 80 feet, the pyritic contents have been changed into gozzans, which, in some instances, are sufficiently pure limonites to be valuable as an iron ore, for which purpose they were shipped to smelting furnaces in Tennessee and Virginia. The present low prices have, however, put an end, temporarily at least, to this use of the gozzans.

Below the gozzans, and above the unaltered pyrites, is a zone of partly oxidized rich copper ore, which, under the name of "black copper," was the object of the early mining operations of Ducktown between 1850 and 1853, when large quantities of rich ore, averaging 28 per cent. of copper, were raised and exported to Swansea, the total export in those years being valued at £200,000. Smelting on the spot was begun in 1854, but the supply of rich ores fell off rapidly until in 1879 the locality was practically abandoned. Subsequently many attempts have been made to utilize the deposits, but they were generally unfavourably reported upon as being too poor for copper smelting, and not containing sufficient sulphur for vitriol making. The present revival of operations dates from 1890, when an English company, the Ducktown Sulphur Copper and Iron Company, after some unsuccessful trials of a wet extraction process, put up smelting works with Herreshoff furnaces of a smelting capacity of 100 tons of charge in twenty-four hours, two of these furnaces being now in regular operation.

The ore, as raised from the mine, is passed through a rock-breaker and screened, the coarser material going to a picking table where included masses of slate and hornblende are taken out so as to secure a basic ore for smelting. The selected ore is roasted in heaps of 200 tons under sheds; the fine siftings are passed through shelf roasting furnaces. When burnt, the ore seldom contains less than 7 per cent. of sulphur, while the copper rarely falls below 3 or

exceeds 4 per cent. From 8 to 12 per cent. of quartz is required to flux the iron in the furnace, giving a slag with over 30 per cent. of silica. In order to concentrate such an ore to a 50 per cent. copper regulus, an abnormally high blast-pressure is required, from 14 to 16 ounces per square inch, which results in the production of a very large amount of flue dust, which the Author estimates to contain not less than 2½ per cent. of the total copper in the ore. The loss in the slags is, however, much greater, as with the best possible smelting, the slag, even when quite free from shots of metal, will still contain at least 0·7 per cent. of copper, and the utmost vigilance will be required to prevent it exceeding 0·8 per cent.; so that of the total copper in the ore, 3½ per cent., not more than 2·7 per cent. is to be found in the furnace product, or, in other words, besides the losses in the flue dust, amounting to 2½ or 3 per cent., the quick concentration by a single fusion results in a further loss of about 23 per cent. of the copper in the roasted ore. About 17 per cent. of coke from Middleborough, Kentucky, is required to smelt the charge of ore and flux. The Ducktown Company at present smelts about 200 tons of ore per day, and has in addition a small circular water-jacket furnace, which is sometimes used in concentrating the ore furnace metal when the latter is too poor to send away. Under these conditions, a pure blister copper and highly concentrated regulus with 70 to 80 per cent. of copper are produced.

In a new plant which the Author was engaged in erecting for the Pittsburg and Tennessee Copper Company, a system of gradual reduction was proposed, the coarse ore being first burnt in closed stalls connected with a tall chimney to carry off the sulphur gases, and the smalls in a Hasenclever gravitating furnace, similar to that employed for mercury ores in California, and then smelted with slaty or siliceous ore instead of quartz to a coarse metal not containing more than 20 to 22 per cent. of copper. The furnace for this purpose is a rectangular water-jacket measuring 10 feet by 3 feet 6 inches at the twyer level, and 10 feet 6 inches by 4 feet 6 inches at the charging door about 9 feet above the twyers. With a blast pressure of about 6 ounces from 180 to 200 tons per day were smelted. The coarse metal of the first operation cast into thin slabs, was crushed fine, roasted in a gravitating calciner, moulded into bricks with 15 to 20 per cent. of its weight of clay, and converted by a second fusion to fine metal or black copper.

It was considered that by this modification, 93 per cent. of the total copper in the ore might be recovered, but the plan has not been fully tried, as the company suspended operations for want of capital before the works were fully completed. In an accompanying Paper, the Author describes a new form of tipping slag-car adopted at the ore furnace which is similar in character to those used in the Pittsburg iron district, the egg-shaped cast-iron slag-pot of about 2½ tons capacity being mounted upon trunnions upon a car frame, so that when filled it can be drawn away by a locomotive, and tipped sideways on the cinder bank to allow the

liquid contents to run out. When in full work, the furnace makes about 180 tons of slag, or three fillings of the car per hour; or six cars will replace 66 to 75 of the small slag-pots, holding 300 to 400 lbs. each, now generally used.

H. B.

Zinc-Furnaces with built-up Retorts.

By Dr. Steger, Lazyhütte, near Beuthen, Upper Silesia.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, 1894, p. 163.)

By the Silesian zinc-distillation furnaces the usual practice is to employ fire-clay muffles, which material has the following disadvantages:—it is a bad conductor of heat, will not stand a very high temperature, is liable to be acted on chemically, and being more or less porous allows a large quantity of the zinc fumes to escape, so that the loss of zinc by these furnaces is often as high as 25 to 30 per cent.

The furnace described by the Author, and of which longitudinal and vertical cross sections are given, obviates these difficulties by employing arches made of magnesia. These arched slabs are built into the furnace, one above the other, in such a way as to form chambers for the ore of considerable capacity. The flame strikes along under and back over the top of each of these chambers, heating them more effectually and evenly than in the case of the muffles used in the older design of furnaces. The magnesian slabs are two-and-a-half to three times better conductors of the heat than fire-clay, are not porous, withstand a high temperature, and being very hard are not so quickly worn out as the clay muffles by the scrapers used for spreading and removing the ore before and after distillation. It is but slightly attacked by any metal oxides or basic materials, and owing to the strength of the material, it is not liable to injury like the muffles if an explosion of gases takes place in the flues. By employing this class of furnace a great saving in renewal of the condensing tubes is effected. The charging of these retorts is far easier than the muffles, and the workmen are not troubled with the heat and noxious fumes, as these pass off into a separate compartment surrounding the condensing tubes. Sunday work is also avoided, as with rich ore the complete distillation of a charge requires a whole day.

R. E. C.

Mining and Treatment of Quicksilver Ores in Mexico.

By W. H. Rundall.

(Engineering and Mining Journal, vol. lix., 1895, p. 607.)

Quicksilver ores occur at a great number of localities in Mexico. The deposits at Guadalcázar in the State of San Luis Potosi and at Huitzuco in the State of Guerrero, are, however, the only ones of economic importance at the present time. Although the existence of cinnabar at Guadalcázar seems to have been known to the Indians before the advent of civilization, the deposits first came into prominence in 1840. The prevailing rock of the district is limestone. No fossils are known to occur in it, and it does not stand in such relation to other strata as to render a stratigraphical determination of its age possible. Porphyry and granite also occur, enclosing veins of silver ore, which were formerly mined on a large scale. The quicksilver is, however, confined to the limestone, and the deposits are traceable over a distance of about 30 miles to the north-west of Guadalcázar. The most important deposits occur at a distance of from 4 miles to 9 miles from the town, at elevations of 400 feet to 700 feet above it. The two most productive mines are the Trinidad, owned by an English company, and the Nuevo Potosi, owned by a local company. The ore at the latter mine occurs in connection with irregular shoots of clay, mixed with boulders of a dark-coloured shale. Both the shale and the clay contain fluorspar, calcite and sometimes barytes. The ore is extracted through a vertical shaft, and an exploration adit has been driven into the hill at a depth of 420 feet below the surface of the shaft. The lowest point to which the main ore shoot has been followed is 275 feet below surface at the shaft. On coming from the mine, the ore is tipped on to screens, the smalls being taken to 10-ton ore-bins and the larger stones being broken down to pass a $\frac{3}{4}$-inch ring, sampled, and tipped into bins. The ore is treated in muffle furnaces with cast-iron condenser and brick sedimentation chambers, the metal being drawn off once a week.

At the Trinidad mine, the ore occurs in a very irregular manner in limestone, which is largely replaced in parts by gypsum. There is one main ore-shoot which has been followed for a length of 650 feet and for a depth of 200 feet. At one point a large body of soft black ore was discovered, averaging 7 per cent. to 10 per cent. of mercury, enclosed in gypsum. The ore, when occurring in the gypsum, is usually a selenide of mercury. About 20 miles to the north-west of Guadalcázar there is a mine, now abandoned, which has been opened to a considerable extent. Quicksilver ores are extensively distributed over the whole of the surrounding district, but only at the points mentioned have they been worked on anything like a large scale.

B. H. B.

On the Preparation and Properties of Pure Molybdenum.

By H. MOISSAN.

(Bulletin de la Société de l'encouragement de l'Industrie nationale, June 1895, p. 743.)

The Author has succeeded in obtaining metallic molybdenum in fused masses practically free from carbon by the following method. Pure molybdate of ammonia finely powdered is heated in quantities of one kilogram in a covered clay crucible for one and a half hours in a Perrot gas furnace. The ammonia is volatilised, leaving bluish-grey powder of molybdic acid (MoO_2) in the crucible, the yield being from 76 to 78 per cent. of the weight of the salt treated. The oxide so obtained is mixed with sugar-charcoal in quantity insufficient for complete reduction; 300 of oxide to 30 of carbon. The mixture, packed into a carbon crucible, is then subjected to the calorific action of the arc produced by a current of 600 amperes at 60 volts for a period of six minutes, care being taken to prevent complete fusion of the metal, so as to keep a layer of solid material in contact with the crucible, which would be rapidly attacked if the charge was completely fused. Under these conditions the metal may be kept perfectly free from carbon, and more than a kilogram may be easily obtained in an hour. The analyses of four samples gave:—

Molybdenum	99·98	99·37	99·89	99·78
Carbon . .	0·00	0·01	0·00	0·00
Slag . . .	0·13	0·28	0·08	0·17

When obtained by this method molybdenum is a tolerably soft metal, can be easily filed and polished, is malleable when hot, and does not scratch glass. Its specific gravity is 9·01. If a fragment is bedded in charcoal powder and heated for several hours to a temperature of about 1,500° Centigrade, cementation ensues, a small quantity of carbon is taken up and the metal becomes harder than glass. The cemented metal, when heated to 300° C. and chilled in cold water, becomes brittle and so hard that it scratches quartz. It is but slightly oxidizable in the air at temperatures below a dull red heat, and becomes coloured on the surface like steel. At about 600° C. it begins to oxidize, is converted into molybdic acid, which is volatile, so that the mass of metal may entirely disappear without melting. The action of oxygen is similar but more rapid, so that combustion takes place with vivid incandescence.

Carbide of Molybdenum.—When the reduction of the oxide in the electric furnace is effected with excess of carbon, substances containing carbon, both in combined and graphitic condition as in

cast-iron, are readily obtained. Their density varies from 8·6 to 8·9. When saturated with carbon the metal is more fusible than pure molybdenum and is intensely hard; but when the proportion of carbon is only 2½ per cent. it is difficult to break it with a hammer. The point of saturation seems to correspond to 5·88 per cent. or the formula Mo_2C. This runs very liquid and may be easily cast into ingots from 8 to 10 kilograms' weight. The liquid metal dissolves carbon very readily, but the excess above this quantity separates out on solidification as graphite; but with less than 5 per cent. no graphite is found in the metal which is white, as shown in the following analyses:—

—	White metal.			Grey metal.	
Molybdenum . .	95·83	..	..	..	92·46
Carbon combined.	3·04	3·19	2·54	4·90	5·50
„ graphitic	0·00	0·00	0·00	0·00	1·71
Slag	0·74	0·53	0·62	..	..

The carburised metal, like cast-iron, may be rendered superficially malleable by closely covering it with powdered oxide of molybdenum and heating for several hours; this produces a skin of the pure metal, which can be filed and polished. The Author considers this decarburation of the solid metal at a temperature far below its melting point to be due to the permeability of the metal to the vapour of molybdic acid. The volatility of its oxide seems likely to render molybdenum of value as a deoxidizing agent in steel works in the place of manganese or aluminium; for although the latter is an energetic agent, it has the inconvenience of giving a solid and infusible oxide (alumina), while the molybdenum oxidizing would produce a stirring action in the bath, leaving nothing behind, or if in slight excess it would have no effect on the malleability and tempering properties of the steel. For this purpose, however, the solid metal would be necessary, as that in a pulverulent form produced by reduction of the oxide with hydrogen is useless, as it merely burns to waste on the surface of the bath without affecting the metal below.

H. B.

North Carolina Monazite. By H. B. Nitze.

(Advance Proof, Transactions of the American Institute of Mining Engineers, March, 1895.)

Monazite, which is a phosphate of the rare elements, cerium, lauthanum and didymium, and also contains oxide of thorium and silica, has of late become a mineral of commercial importance; its economic value lying principally in the oxide thoria, that being one of the constituents in the manufacture of the mantles for the Welsbach and other incandescent gas-lights. Although it is somewhat widely distributed, it has until now only been found in commercial quantities in Brazil, Siberia, Norway, and the States of South and North Carolina. In the latter State it occurs in the sands and gravels of the stream-beds over an area of from between 1,600 and 2,000 square miles, the primary source of the mineral, as well as of the many other rare species, Zircon, Xenotime, Fergusonite, &c., with which it is associated, being the crystalline gneiss and schists, of which they form accessory constituents in the form of scattered grains or crystals through the mass. The material produced from the disintegration of the rock is deposited on the water-courses, where it is subjected to a natural process of partial sorting and concentration, the richest portions of the deposits being as a rule found near to the head waters of the streams. The specific gravity of monazite ranges between 4·9 and 5·3, and the hardness is from 5 to 5·5, or between that of apatite and felspar. As the percentage of thoria is variable in different sands, the value of the mineral varies accordingly, and must be determined by careful chemical analysis. Some monazite contains practically no thoria; the transparent greenish and yellowish-brown varieties are stated to be usually the richest in that earth. The highest class of sand from Brindletown contains from 4 to 6 per cent., that from Gum Branch 3·3 per cent., but the proportions may fluctuate considerably even in the same locality. It also depends upon the concentration of the monazite in the cleaned sand, which necessarily includes many of the associated heavy minerals, such as garnet, zircon, telluriferous iron ore, rutile, corundum, &c., which cannot be perfectly eliminated, so that, even after repeated washing and separation with a magnet, the product is not pure monazite. A concentration up to 60 per cent. of that mineral is considered a good result.

The thickness of the stream-gravel deposits is from 1 to 2 feet, and the width of the mountain streams in which they occur is seldom over 12 feet. The washing is done in sluice-boxes about 8 feet long and 20 inches square. Two men work at a box, one digging and feeding in the gravel, while the other works it up and down with a gravel-fork or perforated shovel in the sluice, in order to stream away the lighter sand. At the end of the day's work the sand deposited in the boxes is cleaned out and dried, and if it contains magnetite it is treated with a magnetite, and is

then ready for packing and shipment. From 20 to 35 lbs. of cleaned monazite sand per hand is considered a good day's work. The value of the best kind is from 6 to 7 cents per lb. at the diggings.

The produce of the district in the years 1893 and 1894 has been as follows:—

	Value. Dollars.	
1893.		
110,000 lbs. at 6 cents	6,600·00	
20,000 „ 5 „	1,000·00	
130,000	7,600·00	(£1,583 6s.)
1894.		
460,000 lbs. at 6¾ cents	31,050·00	
80,000 „ 6 „	4,800·00	
6,855 „ 5 „	342 75	
546,855	36,192·75	(£7,540)

H. B.

Tests of Compound Plates of Copper and Lead.

By M. Rudeloff.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1895, p. 73.)

The fact that lead coverings used to protect iron vessels against the attack of acids, sooner or later scale off, led the Frankenthaler Kesselschmiede Velthuysen Company to the production of a compound plate of copper and lead. One great advantage of this plate over a simple lead covering is that both metals are so intimately united, that in ordinary working the stresses and temperature changes produce equal alterations of form. The above Company ordered a test of the compound plates; sending a plain copper plate and two compound plates, that is, copper covered with lead on one side. The copper plates of the three specimens were taken from the same block.

Tests were made as to the intimacy of the union of the two metals by bending the compound plate at ordinary temperature and at 250° C., and also by repeated temperature changes. Tests were also made on the extension of the pure copper, the pure lead, and of the compound plate, under tension at ordinary temperatures and at 250° C.

From the scientific interest of the subject, it seemed worth while to supplement the tests ordered by the Company, and for this purpose three additional plates were obtained, viz.:—A compound plate of copper with lead covering on both sides, a compound plate consisting of two copper plates united by an inner layer of lead, and a plain copper plate.

Results of Experiments.—By repeatedly bending the compound plate, the lead covering soon gave way in itself, but did not break loose from the copper.

The influence of repeated changes of temperature was investigated by bending a plate into a circular arc of 3·6 inches' radius. By heating to 250° C. and then cooling either suddenly or slowly, the following changes were observed:—

(1) The chord of the arc of the simple copper plate, originally 6·6 inches long, increased 0·02 inch by heating to 250° C. On slowly cooling, the chord length was 0·012 inch less than originally. On repeating this test, the same phenomena were observed.

(2) The changes of form of the bent strips of the compound plates were much greater than those of the simple copper plate, both on the first change of temperature, and also on repetition.

(3) The lengthening of the chord in consequence of heating was a little greater when the copper was inside than when outside. On cooling, the chord length of the strip increased when the copper was inside, but slowly diminished when the copper was outside.

The Author discusses the observed effects, and advances explanations.

The tension tests clearly show that heating to 250° C. impairs the strength of the compound plate much more than that of a simple copper plate; the double copper plate with inner layer of lead is most weakened, the copper plate with lead covering on both sides least.

Comparing the extension of the separate metals in the compound plate, that of the copper is reduced, while that of lead is increased; an explanation of these phenomena is given at length.

An investigation of the distribution of the total load over the two metals is given.

The Paper is accompanied by numerous tables and diagrams.

A. S.

Accumulator-Traction in Paris. By J. Laffargue.

(L'Industrie Électrique, 1895, p. 209 *et seq.* 5 Figs.)

The Author states that a full description of the works connected with the electric tramways to St. Denis in Paris was given in the issue of the Industrie Électrique for the 10th of March, 1892, and in the issue of the same journal for the 10th of May, 1895, an account was given of the details of working which had been submitted by Mr. J. Sarcia to the Société Internationale des Électriciens. The Author has recently had occasion to examine the improvements made in the methods of charging the cells, the construction of the new positive plates, and the fitting of the new cars. The generating plant at the charging station consists of three semitubular boilers with two water tubes of 1,291 square

feet heating surface, working at a pressure of 150 lbs. per square inch; two Corliss engines by Lecouteux and Garnier, developing 125 HP. at 70 revolutions per minute, and each driving by belting a Desroziers dynamo, developing 260 volts and 250 amperes, and one Edison lighting dynamo giving 110 volts and 75 amperes. A third Corliss engine of 150 HP. at 160 revolutions per minute drives direct a Desroziers dynamo similar to the other two.

Some time ago two Desroziers dynamos, developing 35 volts and 200 amperes, were put down, and these are coupled in series with the dynamos of 260 volts. The accumulators are now charged at two different potentials, 250 and 280 volts, whereas, formerly, a constant potential of 265 volts was used; but then the current was very high at starting and gradually fell almost to zero.

Now the charging is begun at 250 volts with a current of 70 to 80 amperes, and as soon as this falls to 10 or 15 amperes the smaller machines are coupled on in series; the potential is thus raised to 280 volts, and the charging current rises to 70 amperes, afterwards falling gradually.

Mr. Sarcia has already explained that the original positive plates of the battery, in which the active material is chloride of lead, gave good results. After running 93,150 car-miles the deterioration was very slight. The positive plates, however, were very unsatisfactory, as they rapidly deteriorated, and the peroxide of lead fell away and became useless after having run 8,694 car-miles. In order to obviate this difficulty the Société pour le travail électrique des Métaux has adopted a type of positive plate, having a central core pitted all over to receive the peroxide.

The active material still falls away badly, but it can be collected at the bottom of the cells and used again for repasting the plates. With these positive plates the discharge current has been increased, and the type of battery used for the car described below has now fifty-six cells, each containing nine plates, measuring 7·87 inches by 7·87 inches, the total weight being 3,740 lbs.; and this battery replaces one of 108 cells, each having eleven plates of the same size, and weighing 6,600 lbs. in all.

Experiments in electric traction were begun upon this line in 1892, and the existing cars were altered to suit the new service; as, however, the old cars were not very satisfactory, a new type of car has now been built and equipped jointly by Messrs. Bourdon and Garnier and the firm of Breguet. The new car is carried upon a truck having four wheels, and a wheel base of 6·23 feet. The total weight in working order is only 11·7 tons instead of 14 tons for the old cars. The top of the car is roofed in and projects at one end over the end platforms.

The battery is contained in a case which is placed under the car between the two axles, and it is hung by four steel hooks fixed to the truck and is supported by wooden slides. On arrival at the depot after a journey this box is drawn out, and another case, containing freshly-charged cells, takes its place; the whole operation only requires two or three minutes.

Two powerful shunt-wound motors are used, each one of which drives the axle by means of a single gear. The output of each motor is 10 kilowatts, and they run at 500 revolutions per minute, instead of 1,200 to 1,500 which was their former speed. The controlling switch is provided with a number of contacts, so that the coupling of the field magnets, armatures and certain resistances is altered. A very powerful electric brake is used which consists in short-circuiting the armature. Trials have proved that the employment of this method rendered the use of ordinary brakes unnecessary, but in order to comply with the traffic regulations a hand-brake had to be added.

The motors enable electric energy to be taken up on descending inclines, and this may reach as much as 18 per cent.; this is very advantageous, as the motors act as dynamos and give a small charge to the cells just after their period of greatest discharge.

The Author gives some curves taken by a recording wattmeter upon the journey. From the results of a trial made on the 24th of April, 1895, the following details were obtained. The consumption of energy is given in ampere-hours.

Distance run from the Dépôt Saint-Denis to the Madeleine and back = 11·82 miles.

Weight of loaded vehicle	12 tons.
Journey to the Madeleine lasted	56 minutes.
Energy used	44·51 ampere-hours.
„ produced	7·77 „
Return journey lasted	55 minutes.
Energy used	43·13 ampere-hours.
„ produced	9·05 „
Total energy used	87·64 „
„ „ produced	16·82 „
Real expenditure of energy	70·82 „
Remaining in battery	25·00 „
Energy expended per train-mile without allowance for energy produced	0·616 „
Energy expended per train-mile with allowance for energy produced	0·497 „
Average potential difference	105 volts.

The Author observes that very great improvements have been made in electric traction by means of accumulators, and the cost of working has been diminished. He considers that this system offers a suitable means for traction inside Paris, while possibly the overhead wire may be found better outside the fortifications.

E. R. D.

The Continuous-Current Dynamos of Messrs. F. Balas and L. Couffinhal. By P. Girault.

(L'Industrie Électrique, 1895, p. 171.)

The Author reviews the various methods which have been tried in order to obtain automatic regulation of the lead of the brushes in dynamos; he considers that the apparatus used in constant current dynamos is not, as a rule, suitable for constant potential machines. He favours, rather, those methods of construction which tend to reduce the effects of armature reaction. After describing the compensating winding method and its disadvantages, he proceeds to give the following description of a dynamo in which the magnets are subdivided axially, so that the cross induction has to pass an air-gap.

A 55 kilowatt dynamo, made by Messrs. Balas and Couffinhal, has been fixed in the electric central station at Saint-Étienne, and supplies on a full load a current of 500 amperes at 110 volts at 500 revolutions per minute. It is of the four-pole type.

The armature is of the Gramme ring type, the core of which is composed of soft iron plates 0·0078 square inch thick. These plates are first coated with coal-tar oil to prevent rust, which often penetrates the insulating material. They are afterwards piled upon two bronze spiders, each plate being separated by a very thin sheet of paper. The two spiders are afterwards fixed on the shaft, upon which they are keyed and firmly pressed together by six steel bolts. These bolts are placed comparatively close to the shaft, so that they neither obstruct the windings, nor are subject to Foucault currents. The core thus formed is insulated along its periphery by means of two superposed cloths covered with bitumen, between which are placed thin sheets of mica; upon the lateral face and in the interior, insulation is obtained with vulcanized fibre. The plates of the collector are insulated by mica. The section of the iron of the ring—that is to say, that through which the whole of the flux emanating from one pole passes—is 76·725 square inches without the insulating material. The induction permitted is 12 kilograms. The outside diameter of the core is 21·079 inches. It is wound with a conductor in 120 sections of two turns each, the conductor being formed of four parallel wires, each of 0·113 inch diameter, insulated by two layers of cotton, then gum-lacquered.

The framework of this four-pole machine consists of four pieces of soft cast-iron, the planes of intersection passing through the axis of the machine and dividing the pole-pieces into two equal parts. These four portions of the framework are supported, one on the other, only by the bronze block separating them, so that between the two contiguous pieces of cast-iron, forming a pole-piece, there is an empty space of two centimetres constituting a very strong resistance to the transverse fluxes. These four pieces

are connected together by eight bronze bolts pressing upon ear-pieces fixed above the place reserved for the magnet coils. These bolts go through the bronze plates and the cast-iron ear-pieces. The lower segment of the magnet is cast with the foundation plate.

The induction in the cast-iron portions of the magnetic circuit is six kilograms. This induction and that of the armature area are perhaps a trifle weak, and for this reason the dynamo is heavy, but the builders estimate that this weight is necessary for the machine.

The section of the cast-iron circuit is 206·15 square inches for the total flux emanating from one pole. Its length is 47·28 inches. The diameter of the boring of the pole-masses is 22·14 inches, which gives 1·064 inch as the total length of the air-gap. The electric losses are 1,100 watts in the magnet, and 2,100 watts in the armature. The cooling surfaces are, 1·86 square inch per watt wasted in the magnet coils, and 0·775 square inch per watt lost in the armature, counting only the surfaces which are well ventilated. The excitation required by the four magnet coils in open circuit is 20,600 ampere-turns, which is obtained with a current of 9·2 amperes through 2,240 turns of wire of 0·121 inch diameter insulated by a layer of cotton. At full load a supplementary excitation of 1,800 ampere-turns only is required on the four-pole pieces for compensating the reactions of the armature.

R. W. W.

Transmission of Power by Polyphase Currents. By A. Hiss.

(L'Éclairage Électrique, vol. iii. p. 337.)

The Author describes the outfit for the distribution of power in the works of Messrs. Weyher and Richemond, who manufacture alternate-current motors under the Brown patents. The works were previously driven by three separate engines erected in different parts of the buildings. Now, the whole of the power is generated at one spot, and distributed by means of diphased currents.

A battery of five boilers has been installed in the generating station, three of which are used for driving the main engine, and the other two are employed for the testing engines. The main engine is capable of developing 400 HP. at 60 revolutions per minute, but its most economical load is 200 HP. It is of the horizontal kind, and automatic oiling has been made a special feature in the details. This engine drives a counter-shaft by which the following machinery is actuated by belting:—Three two-phase alternators of 130 HP. each; one small three-phase alternator for testing purposes; and a direct-current dynamo of 11 kilowatts used for the excitation of the alternators. The three

alternators are each capable of giving 400 amperes at 110 volts in each circuit, *i.e.*, 88 kilowatts per machine. The losses in these alternators have, the Author states, been most carefully determined by Mr. Boucherot, who obtained the following figures in watts:—

——	Full Load.	Half Load.	One-tenth Full Load.
Losses in the armature	2,280	570	20
" " " magnets	1,520	1,460	1,400
Friction	640	640	640
Air-resistance	1,000	1,000	1,000
Hysteresis	1,160	1,130	1,100
Foucault currents	1,760	1,700	1,600
Useful output	88,000	44,000	8,800
Total power supplied	96,360	50,500	14,560
Commercial efficiency . . . per cent.	91·3	87·2	69·5

The armature reaction is small, so that the excitation current need only be varied some 8 to 10 per cent. between no load and full load. The Author refers to the methods of testing, and draws comparison between direct-current and alternate-current machines on the point of efficiency.

The following motors are placed in different departments:—

——	Number of Motors.	HP. given by Each Motor.	HP. given by Total.	HP. required by Motor.
Test-room	1	30·0	30·0	33·0
Large brass-finishing shop	1	45·0	45·0	49·0
Small " " "	1	13·0	13·0	14·6
Winding shop	3	1·5	4·5	6·1
Forge	1	1·4	1·4	1·9
Lifts	1	3·0	3·0	4·0
	1	5·0	5·0	6·0
Traveller	1	8·0	8·0	9·3
	2	1·4	2·8	3·8
Fitting shop	1	45·0	45·0	49·0
Pattern shop	1	20·0	20·0	22·2
Machine shop	1	30·0	30·0	33·0
Erecting shop	1	20·0	20·0	22·2
	1	30·0	30·0	33·0
			257·7	287·1

The Author proceeds to describe some improvements in electrical condensers devised by Mr. Boucherot for alternating-current works and also improvements in motor design.

The article is well illustrated by fifteen blocks.

R. W. W.

Producer-Gas Engines and the Electric Transmission of Power. By — Leneveu.

(L'Industrie Électrique, 1895, p. 218 *et seq.* 5 Figs.)

The Author describes a new power installation which has recently been put up in the chemical manure works of Mr. Linet, at Aubervilliers, near Paris. Owing to the increase in the size of the works it was necessary to increase the available power; and as the space covered by the works is very great, it was decided to use electric transmission of power and producer-gas plant. The atmosphere was full of dust, but previous trials have shown that dynamos can support such a condition.

It was decided to use three gas-engines of the Simplex type, by Messrs. Delamare-Deboutteville et Malandin, driven by gas from producers of the Buire-Lencauchez type. Messrs. Matter & Co., of Rouen, who are the manufacturers of the latter apparatus, also provided the whole of the shafting, clutches, &c., for driving the dynamos from the engines; while the Gramme Company supplied all the electrical part of the plant, such as generators and motors, and also a dynamo used for electric lighting.

The motive power is supplied by the three Simplex engines, each of 80 HP., and these can be used either separately or together, according to the amount of work to be done. Each engine drives a dynamo by means of belting and a shaft placed below the floor. A battery of two producers, with purifiers and gasometer, supplies the gas. Besides the three gas-engines and four dynamos already alluded to, there are also two steam-engines and one pump; and it was found necessary to arrange the shafting so that either the large steam-engine or one or more of the gas-engines could be used to drive one or more of the dynamos.

The space in which the plant is installed being very confined, it was found necessary to do without countershafts and to employ two main lines of shaft only. The Author then gives details of the construction of these shafts and couplings, from which it appears that a special type of coupling is used, with movable keys, and the shaft has to be stopped to put the couplings in or out of gear.

Each particular engine drives the corresponding portion of shafting by a belt which runs on either a fast or loose pulley upon the shaft. The engine-belts, which are acted upon by belt-forks, are of ordinary leather, while those used for the dynamos are of orange-tan hide, and the main belt is of cotton. Test-pieces were taken out of each belt and tested before acceptance.

The electric installation has been designed for the ultimate installation of three generators of 56 kilowatts each, and of about twenty motors, varying in power from 4,000 to 15,000 watts, for the transmission of power, and an electric-lighting dynamo of 56 kilowatts for both arc- and glow-lamp lighting. At present

only one generator and five or six motors and the lighting machine are installed. The generator develops 450 amperes at 125 volts, and is compound-wound. The other dynamo is shunt-wound, and will give a maximum potential of 165 volts, so that it may be used for charging a battery which will be eventually installed. The motors are of the bipolar Gramme type, shunt wound, running at a constant speed independent of the load, and with carbon brushes fixed permanently but causing no sparking.

From tests made in the works of the Gramme Company by Captain Leneveu it appears that the efficiency of the generator is 77·5 per cent. when developing 130 amperes, and this rises to 91 per cent. for the full load of 450 amperes. The efficiencies of the motors obtained by brake-tests were as follows:—

Volts.	Amperes.	Revolutions per Minute.	Efficiency.
			Per Cent.
125	125	900	89
120	63	1,050	88
120	38	1,072	86

Although it is intended that as far as possible one particular generator shall supply a special group of motors, yet to assure the proper working of the business it will be possible to use currents from any generator for any motor.

The Author describes the switch-board, which has means for coupling a recording apparatus into any circuit. A ten hours' test of the whole plant was made; but as it was considered desirable to take this at full load, although all the installation was not complete, an adjustable water-resistance had to be used. It is stated that this method allowed of much easier manipulation than if the actual machines had been used, as it was far simpler to alter the load rapidly with this apparatus. The results obtained in this ten consecutive hours' test were as follows:—

Mean power developed by the gas-engine	71 HP.
Maximum power developed by the gas-engine	86 HP.
Mean revolutions per minute	123
Maximum revolutions per minute	124
Minimum revolutions per minute	120
Mean speed of the dynamo	378 revolutions per minute.
Mean output	371 amperes at 124 volts.

The speed of the gas-engine had been specified as 125 revolutions per minute, so as to allow for slight slip in the couplings; but that never occurred, and so the speed of the dynamo was higher than the specified speed of 360 revolutions per minute. This test

was made on the 31st October, 1894, by an engineer of the firm of Matter, under the direction of Captain Leneveu and the engineer of Mr. Linet. As this was satisfactory, the brake-test was made on the 2nd November, 1894. A rope-brake was used, with ropes 1·17 inch diameter. One end of these ropes was loaded direct, and the other ends were attached to locomotive spring-balances supported by the overhead crane. The pulley used was of U form, without arms, and water was run in and out of the rim for cooling purposes. The number of revolutions of the engine was taken by a totalizing counter, and a Crosby indicator was used on the cylinder. Five or six successive curves were taken on the same card, and these cards were taken every fifteen minutes for a period of four hours.

The Author explains in detail the method employed for measuring the coal consumed. Although the speeds of the engine were purposely varied while running by altering the governor, it was proved that the latter would regulate within 5 per cent. if properly set. The following is a Table of the results of the tests made on the 80-HP. gas-engine on the 3rd November, 1894:—

Diameter of brake-pulley	7 feet
Diameter of cylinder (gauged)	22·8 inches
Stroke of piston	30·0 inches
Total weight of coal consumed	510·0 lbs.
Length of test	4·19 hours
Mean revolutions per minute	120·220
Mean B.HP.	81·42
I.HP.	105·81
Efficiency	76·9 per cent.
Maximum B.HP. (no explosions missed)	95·810
Maximum I.HP.	124·518
Coal consumed per hour	118 lbs.
" " B.HP. hour	1·46 lbs.
" " I.HP. hour	1·12 lbs.

E. R. D.

The Blondel Photometers. By E. Hospitalier.

(L'Industrie Électrique, 1895, pp. 185, 186. 4 Figs.)

The Author states that Mr. Blondel has brought out a new type of photometer for the direct determination of the mean spherical intensity of a source of light, and this appears to give quicker, easier, and more certain results than have hitherto been obtainable.

The source of light to be measured is enclosed in a hollow sphere, which is carefully blackened on the inside and provided with one or more segmental slits cut in a vertical direction. The light passing through one of these openings having the dihedral angle α is a certain proportion of the total light given out. If the rays are given off symmetrically by the source of light, it is sufficient to measure the intensity of the light passing out through

the opening, and multiply this by $\frac{a}{2\pi}$ in order to obtain the total flux Φ and the mean spherical intensity

$$I m = \frac{\Phi}{4\pi}.$$

If the source of light is not symmetrical, it is sufficient to take a dihedral angle a, which is a fraction $\frac{1}{n}$ of 2π, and to make n observations by turning the globe each time $\frac{2\pi}{n}$ of the circumference in order to measure the whole flux by fractions.

If it be desired merely to measure the flux of rays for the lower hemisphere, it is only necessary to cover the upper half of the globe with an opaque cap. Such is the general principle of the apparatus, and it is made use of as follows:—In order to measure the light emitted by the segmental slit in the globe, the effect is concentrated by means of a curved mirror upon a diffusing screen, which may act either by transmission or refraction. It is essential that the rays should all fall in approximately the same direction, or at least in directions only slightly different from the normal. The admissible variation appears to be 40° for certain diffusing screens such as opal glass, but should not exceed a few degrees for paper; it depends, however, on the degree of exactitude desired in the results. A photometer is placed in such a position relative to the diffusing screen that it may receive the rays diffused by the latter whether by transmission or refraction, and be placed in such a position that the angle of emission of the rays falling upon the photometer is sensibly constant over all the illuminated portion of the screen. The second screen of the photometer is illuminated by a standard light, which is used for comparison.

The Author then discusses the use of certain equations which are applicable to the apparatus. As a reflector Mr. Blondel uses by preference either an elliptical or parabolic mirror. The edge or rim of this mirror is placed in the vertical plane passing through the axis of the source of light and normal to the axis of the apparatus. It is thus possible to obtain a measurement of the illumination of the half sphere, and two tests give the total spherical illumination. With such an arrangement as the above, however, the angle of incidence of the rays upon the glass varies greatly, and this causes a variation of 5 to 6 per cent. in the reflecting power at different points of the mirror. After numerous trials Mr. Blondel has found it preferable to use two vertical segmental openings in the sphere, each opening being about 18°, and thus limiting the variation in the angle of incidence to about 1 per cent. The mirror in this case is preferably elliptical and placed about 10 feet from the screen, and the photometer also at 10 feet distance on the other side. A room about 20 to 25 feet long is then sufficient for test purposes.

Mr. Blondel has given the name of lumen-meter to his apparatus, and one of the zone type has been made by Messrs. Sautter, Harlé & Co. at their own expense. The first apparatus was made in 1892 with a silvered copper reflector; but it was found difficult to retain the polish of such a surface, and therefore a cut and silvered glass reflector of the type used in projectors has been used since. An opening at the top allows of the introduction of arc-lamps into the sphere, which is solidly attached to the mirror. For lamps or gas-burners the apparatus can be turned on pivots so that the opening can be brought below. To facilitate the introduction of lamps, a portion of the front hemisphere can be easily removed, as it is only held by two hooks. Other details are given of a smaller type suitable for less accurate work.

The Author then quotes results obtained by Mr. Jean Rey with this apparatus. An arc-lamp was used in which carbons of various sizes were employed.

TOTAL ILLUMINATION IN "LUMENS" EMITTED BY AN ARC-LAMP WITH DIRECT CURRENT.

Amperes.	Volts.	Diameter of the Carbons in Millimetres.	
		+ 21 − 13	+ 14 − 9
		Lumens.	Lumens.
20	44	7,900	21,330
25	44	9,430	33,830
30	45	16,260	46,330
35	46	28,100	61,330

The lumen is the unit of illumination in the system which Mr. Jean Rey and Mr. Blondel have adopted, and is equal to the total light emitted by a source of light having the intensity of one decimal candle in a solid angle equal to unity. The figures in the Table divided by 4π give the mean intensities in decimal candles. The figures show that by a judicious choice of carbons at least three times the illumination can be obtained possible with another size of carbons.

E. R. D.

Portable Search-Light Apparatus. By E. J. BRUNSWICK.

(L'Électricien, 1895, p. 113 *et seq.*)

The Author commences by stating the well-known fact that the use of search-light apparatus in the fieldwork in the army has been greatly retarded by the difficulty of transport due to the

weight of the necessary parts. He then proceeds to describe in detail the various parts of this search-light plant for field purposes designed by the Brequet firm. The boiler is of the Trepardoux vertical type; and is cylindrical and hollow. In the centre there is another cylindrical vessel forming the inner chamber of the boiler and the steam-dome. The two parts are connected by a number of small tubes which give a large heating-surface. The following advantages are claimed for this construction:—

(1) Dividing the water to be vaporized into a great number of tubes.

(2) The production of a rapid circulation over the heating-surfaces.

(3) A system of drying the steam by passing the hot gases over the steam-dome.

The following are details of a boiler of this type:—

Useful power on the shaft of the generator served by the boiler at the trial	11·15 HP.
Dimensions of the boiler	2 feet 6 inches diameter and 5 feet 2 inches high
Weight of boiler empty	1,430 lbs.
Weight of boiler with water	1,670 lbs.
Heating-surface	64·5 square feet
Grate-area	3·05 square feet
Coal burnt per useful HP. hour	5·7 lbs.
Water evaporated per lb. of coal	6·51

The steam-motor used was the Laval turbine, described elsewhere,[1] which also gave exceedingly large output per weight owing to its high speed.

The dynamos were of the Manchester type, of the following weights, &c.:—

—	No. 1.	No. 2.	No. 3.
Speed	3,000	2,400	2,400
Voltage	70	80	80
Current	40	75	120
Watts	2,800	6,000	9,600
Total weight . . . lbs.	593	860	980
Commercial efficiency . . . per cent.	76	82	85

Automatic lamps were used, made by the Brequet firm, with the well-known Mangin reflectors. The weights of these lamps complete were as follows:—

	Lbs.
For a projector 40 centimetres to 60 centimetres diameter	44
,, 60 ,, 90 ,,	66

The gear was mounted as follows:—The boiler, Laval turbine

[1] *Ante*, p. 416.

and coupled dynamos on one carriage, and the propeller with wire-drum, &c., on another. The weights complete then come out as follows:—

Size of mirror . . . . . centimetres	40	60	90
HP. of turbine	5	10	15
Weight of generating plant and carriage complete . . . . lbs.	3,640	4,620	5,500
Weight of projector and carriage complete . . . . lbs.	990	1,320	1,870
Total lbs. . . .	4,630	5,940	7,370

The description is illustrated by a large number of blocks of details of the plant.

R. W. W.

The Breslau Electric Tramway.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1895, p. 133.)

This tramway was built in 1893 by the Allgemeinen Elektrizitäts-Gesellschaft zu Berlin, and has now been in operation for nearly two years. On account of the very heavy traffic in the streets of Breslau the rails weigh 85·5 lbs. per yard. Overhead conductors, of silicium bronze wire 0·28 inch diameter, are used, the conductor being supported from a wire cable. The rails serve as the return-wire. The total length of the tramway is 8½ miles; the line being double except in the centre of the town, where the streets are narrow.

The boiler-house contains four Steinmüller-Gummersbach water-tube boilers, each boiler having 1,140 square feet of heating surface. Two boilers are in daily use, the third and fourth act as reserves. The boiler-pressure is 150 lbs.

The steam-engines are three in number, built by the Görlitzer Eisengiesserei und Maschinenfabrik. Each contains one horizontal high-pressure cylinder, and one vertical low-pressure cylinder. The maximum horse-power is 200, the revolutions per minute 150. The high-pressure cylinder has a Collmann expansion-gear, controlled by the governor; the low-pressure cylinder a Meyer variable expansion-gear.

The dynamos are two in number, are belt-driven, and each is provided with two fly-wheels; they make 520 revolutions per minute, and deliver 120 amperes at 500 volts.

The rolling-stock consists of forty motor-cars and forty-five ordinary cars, one electrically driven snow-sweeper, and two salt-distributors. Each motor car has two electro-motors underneath

the floor, and has sitting accommodation for twenty, and standing-room for twelve passengers.

The tramway passes through the busiest parts of the town, while near its suburban termini are many pleasure resorts. The traffic is very varied; on Sundays and holidays over 60,000 passengers are carried. For the ordinary week-day traffic thirty-two motor cars and a few ordinary cars are usually sufficient, but on Sundays and holidays every available car is used. A uniform fare of ten pfenning ($1\frac{1}{4}d.$), for which a journey of $5\frac{1}{2}$ miles may be taken, makes this tramway a very cheap means of transport for a labouring population.

The coal consumption is on the average 0·44 lb. of coal per car-mile. The income is 2·6*d.* per car-mile; 1,200,000 car-miles per year are run.

For the first financial year, which included one half year's working, a dividend of 4·7 per cent. was declared, while for the year 1894 the dividend was 8 per cent.

The Paper is accompanied by a sketch-map, plan of the power-station, and drawings of the engines.

A. S.

Experiments upon Friction in Electric Motors and Transmission Shafting. By S. Hanappe.

(Revue Universelle des Mines, vol. xxx., May, 1895, p. 160.)

These experiments were made on electric motors and transmission shafting in the Electro-Mechanical Laboratory of the École Spéciale d'Industrie et des Mines at Hainaut. In a large number of experiments and researches undertaken in electro-technical laboratories it is at times advantageous to be able to rapidly estimate the approximate yield of a transformation of energy, whilst at others an exact measurement by means of dynamometers is required. In both cases it is necessary to know the power absorbed by friction of the shaft revolving in its bearings for different speeds, or the mean coefficient of friction under the ordinary conditions of speed.

The methods followed, with a view of determining between what limits the power absorbed by subterranean transmission shafting varies, are capable of general application. This fact, combined with the importance of the subject, led to the detailed description of the experiments and their results. The latter bear a relation to the coefficients of friction between the shafts and their bearings, and to the distribution of power absorbed by the electric motors.

A description of the Pieper (Manchester type) and Dulait (Edison-Hopkinson) motors, and of the transmission shafting connecting them, is given, and their principal dimensions—necessary to the calculations and graphical determinations subsequently

undertaken—are shown on diagrams accompanying the article. The dynamometers and electrometers used in the experiments are next described, and the procedure for the determination of the power absorbed by friction under varying conditions recounted. The Dulait motor was lubricated with mineral oil (oléonaphte No. 1, costing 12*s.* 2*d.* per 100 lbs.), to which was added a little petroleum, with a view of reducing its consistency.

A number of experiments enabled the Author to determine the amount of friction developed under varying speeds, and from the curve laid down read off the coefficients of friction by a simple alteration of scale. To obtain true values a double series of experiments was made, with a gradually *increasing* speed and with a *decreasing* speed, and the mean of the two results taken. The difference in the results obtained with an increasing and decreasing number of revolutions is shown in the following Tables:—

TABLE SHOWING EFFECT OF INCREASE OF SPEED.

Volts. (Pieper Motor.)	Amperes. (Pieper Motor.)	Watts.	Number of Revolutions. Dulait Motor.	Number of Revolutions. Transmission Shafting.	Brake Load in Kilos.	Remarks.
25	15·7	..	529	259	2·065	The values of the volts and amperes are not guaranteed absolutely correct.
33·5	14·5	..	580	284	2·165	
39·5	14·4	..	625	307	2·265	
45·3	14·8	..	675	331	”	
53·5	15·5	..	762	373	2·315	
56·5	15·8	..	798	392	”	
62·8	16·8	..	860	421	2·415	
72	17·95	..	975	478	2·580	
69·2	21·45	..	1,180	586	2·765	

TABLE SHOWING EFFECT OF DECREASE OF SPEED.

Volts. (Pieper Motor.)	Amperes. (Pieper Motor.)	Watts.	Number of Revolutions. Dulait Motor.	Number of Revolutions. Transmission Shafting.	Brake Load in Kilos.	Remarks.
87	19·8	..	1,238	608	2·665	The values of the volts and amperes are not guaranteed absolutely correct.
73·7	20·85	..	1,147	563	2·665	
75·6	18·2	..	990	486	2·465	
67·75	17	..	890	438	2·365	
58·5	15·75	..	801	393	2·265	
59·5	16	..	816	399	2·265	
53·4	15·3	..	748	368	{1·185 (*sic*)}	
40·5	15	..	640	314	2·085	
31·5	15·2	..	577	283	1·835	
26	16·4	..	511	251	1·615	

In the following Table are shown the mean brake loads and the coefficients of friction given by formulas deduced from the dimensions and weights of the several parts of the motors and shafting:—

Number of Revolutions.		Speed of Shafts in Metres.		Mean Brake Load in Kilos.	Mean Coefficient of Friction.	Remarks.
Dulait Motor.	Transmission Shafting.	Dulait Motor.	Transmission Shafting.			
400	196	1·150	1·530 (*sic*)	..	..	
500	245	1·420	0·642	2·00	0·0244	
600	294	1·726	0·772	2·10	0·0257	
700	343	2·020	0·900	2·21	0·0270	
800	392	2·300	1·030	2·32	0·0283	
900	441	2·580	1·126	2·44	0·0298	
1,000	476	2·880	1·245	2·55	0·0312	
1,100	540	3·170	1·415	2·65	0·0323	
1,200	588	3·460	1·540	2·75	0·0336	

Of the numerous Tables and curves given the most instructive are those showing the friction produced in the bearings of transmission shafting. In the case considered is clearly seen how this increases when a speed of 2·9 feet per second is exceeded.

Further experiments were made with a new mineral oil, which was applied to some of the bearings, with the result of an increase in the coefficient of friction amounting in the motor to 20 per cent., and in the underground shafting to 33 per cent.

Shortly before these last experiments, and subsequently to those previously made, an interval elapsed during which some masonry work was carried out in the vicinity of the transmission shafting, and the Author considers it quite likely that particles of cement may have introduced themselves into the bearings and been responsible for the large increase of friction. On the other hand, it may have been caused by the use of the new lubricant. The former surmise is, however, borne out by the experience of certain constructors, who have found that the bearings almost invariably run hot at the start in cases in which the paving of the engine-room follows the mounting of the engines. Experiments with neatsfoot oil, as shown in the Tables, give, as a rule, somewhat lower results than those obtained with the use of mineral oils. Up to a speed of 1 metre per second the coefficient increases very slowly, and beyond that figure it rises at a lower rate than that developed with mineral oil.

The Author states that he hopes soon to verify the above experiments with a new apparatus, and to extend those already made.

The last pages of the article are devoted to an analysis of the power furnished to the motors, and show how the amount of energy consumed by the several mechanical, magnetic and electrical

parts of the dynamo machine can be determined by the mode of operation adopted by the Author. Several Tables and diagrams of the power consumed, constructed from figures obtained by experiment and calculation, are given.

J. R. B.

The Annealing of Wire by Electricity. By H. Wedding.

(Stahl und Eisen, vol. xv., 1895, p. 195.)

The Lagrange and Hoho system of heating metals by the resistance to conductivity offered by an envelope of hydrogen produced by electrolysis of water has been applied to the annealing of hard-drawn iron wire by Messrs. H. A. and W. Dresler, of Creuzthal, in Westphalia. The apparatus consists of an electrolysing tank containing a weak solution of salt in water, with a surface covering of petroleum. A plate of lead is placed near the bottom of the tank and connected with the positive pole forms the kathode, while the hard wire is guided through the tank parallel to the kathode by two insulated rollers immersed at about half the depth of the fluid. As it passes downwards it receives the current from the negative pole by a roller contact similar to that of an overhead electric railway, and sets up decomposition in the water with an accumulation of hydrogen around it, so that it immediately becomes red hot through the increased resistance to the current, and is softened without becoming oxidized, as on passing the second roller it is cooled in the upper part of the bath and the protecting cover of petroleum at the top. This arrangement is suitable when the wire is passed through the apparatus at a low rate of speed; but if the motion is rapid, the wire may come out of the water sufficiently hot to fire the petroleum cover. In this case it is better to bring the wire out vertically through a tube filled with the oil, so that a much greater depth of the latter can be used than is possible when it covers the open bath. Wire that is covered with scale, as, for instance, that made by rolling, is rendered bright when annealed in this way, the result being due not to the reducing action of the hydrogen envelope, but to the difference in the rate of expansion between the metal and scale when strongly heated, which causes the latter to break off and fall to the bottom of the tank. For this purpose it is better to place the kathode along one side of the tank, in order to keep it free of the accumulation of scale on the bottom. The tension of current required is about 200 volts. By the adoption of this method the operations of pickling and washing required when furnace annealing is used, and the consequent fouling of the streams with waste acid liquors, are avoided.

H. B.

A Thermo-Chemical Carbon Cell. By DESIRÉ KORDA.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxx., 1895, p. 615.)

On heating a plate of carbon in contact with a piece of barium dioxide, the Author obtained, at a dull red heat, an electromotive force of nearly 1 volt, the theoretical difference of potential, calculated from thermo-chemical data, being 1·58 volt; there was a considerable effervescence, carbon dioxide being given off.

In another experiment, in which the materials were heated in a crucible, the internal resistance of the cell was found to be 13·6 ohms. The Author points out that barium dioxide can be regenerated by exposure to air at 500° C.

Copper dioxide and carbon, separated by a layer of dry carbonate of potassium, gave on heating an electromotive force rising to 1·1 volt, and remaining nearly constant for half an hour. The resistance in this experiment was only 3·2 ohms. A deviation of the galvanometer in the opposite direction, occurring at the commencement of the experiment, was ascribed to the temporary action of vapour of water.

G. J. B.

The Heating and Ventilating of the new Reichstag Building in Berlin.

(Zeitschrift des Allgemeinen Technischen Vereines, p. 75, 1895.)

The quantity of air to be dealt with in ventilating the Reichstag building is very considerable, the hourly supply being about 200,000 cubic metres, while in cold weather 6 million metric calories are necessary to maintain the required temperature. The air is heated partly by steam, partly by warm water, the latter being itself heated by means of steam. The air for the upper parts of the building is heated in separate compartments in the basement, and as it rises it has to pass through mixing valves in which it is mixed with the necessary quantity of cool air. These valves are controlled from a central office, being actuated by means of compressed air, and, as each room is provided with a registering thermometer communicating with the same office, the engineer in charge can, by simply turning a handle, regulate the temperature in any part of the building. Similar arrangements have been provided for regulating the supply of air, which is renewed five times hourly in the session chamber and less frequently in other departments. The air-inlets are in the towers, 115 feet above ground-level. The air first passes through filtering chambers, and in winter is then heated from 50° to 53°·6 Fahr. It is next moistened by sprinklers, and subsequently heated up to the final temperature of 68° Fahr. By this treatment the air entering the rooms necessarily contains a considerable amount of

moisture, but cannot be saturated with aqueous vapour. The vitiated air is removed by suction through a flue communicating with two other towers of the building. The warmed air enters the session chamber through a large channel immediately below the ceiling, and under each seat is an opening through which the vitiated air can be drawn. This part of the system is reversible, and in summer air is drawn in under each seat in the early morning, with the result of cooling the chamber considerably. Twelve large ventilators from 3·94 feet to 6·89 feet diameter, worked by ten electromotors of 72 total HP., provide the necessary currents of air. The maximum circumferential velocity of the ventilators being only 82 feet, no noise is audible. The length of pipes used is about 85,300 feet, mostly of wrought iron. In no instance are these rigidly fixed, but are hung in loops to allow for expansion and contraction.

W. F. R.

Binding-Agents for Consolidating Sawdust into various Plastic Substances. By Dr. Th. Koller.

(Glaser's Annalen für Gewerbe und Bauwesen, July 15, 1895, p. 38.)

Sawdust, regarded as a waste product, is capable of very wide application, but depends mainly for its utilization upon the possession of a suitable binding material. A very common use of sawdust is for the manufacture of so-called "artificial wood," and for this purpose a number of fluids are available. In the first rank may be placed albumen—the serum of blood—which solidifies when heated, and furnishes an admirable binding agent. The sawdust from soft woods may be boiled with a solution of glue and water-glass, by which means the materials are united into a putty-like mass capable of being readily moulded into any shape. By means of powdered kolophonium finely-sifted sawdust can also be compacted into a solid substance. Dissolved glue alone, or five parts of glue mixed with one part of isinglass, slowly warmed in water and carefully filtered, can be employed to bind together the sawdust. The amount of water must be so adjusted that the glue in no case sets into a jelly upon cooling. A small proportion of gum tragacanth can be used with advantage to stiffen the mass, and a little powdered chalk adds to the ultimate hardness of the compound. Kletzinski forms his "wood-paste" from 100 parts of sawdust—preferably from soft wood—together with 100 parts of silicate of alumina, mixed with the requisite amount of water. To these are then added 50 parts of glue, dissolved in 100 parts of boiling water, and the glue solution is intimately mixed with the sawdust, the whole being well kneaded together and rolled into cakes under heavy pressure. The resulting material, which is at first very tender, is repeatedly moistened with a weak solution of potash in water. By this means the wood fibres are

gradually united with a tough, horn-like mass of glue, which is insoluble in water. A waterproof binding material for sawdust is obtained by the use of what is termed "chrome-glue," a solution of glue to which a little bichromate of potash has been added. The direct action of light after kneading together the materials is in this case requisite.

Various cements formed of sawdust are obtained by the use of albumen, glue and casein. Equal parts of sawdust, casein and water yield a good cementing agent. In making wood-cement slabs from sawdust it is usual to employ mixtures of glue and water-glass. Suitable damp-courses may be formed for walls by using a mixture of tar and sawdust. Briquettes are made of sawdust and molasses, the refuse product of the sugar manufacture. Sawdust is occasionally employed with cement and lime to produce mortar. It may also be used with plaster of Paris. If needed for stucco on outside walls, a mixture of one part of cement, two parts of lime, two parts of sawdust, and three parts of sharp sand may be employed with advantage. When sawdust is used in the making of bricks the clay serves as the binding agent, and instead of taking only clay and sand, 50 per cent. of sawdust is added. These sawdust-bricks after being burned should be well wetted, by which means much of the ash together with the alkalies are soaked out. Chloride of zinc, magnesia, and similar substances may also, it is stated, be used to unite together sawdust into a stone-like mass.

G. R. R.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1894–95.—Part IV.

N.B.—Titles in italics refer to Original Papers, and those selected for printing only are further distinguished by the suffix "(S.)" *or* "(St.)," *the latter denoting Students' Papers. Abstracted Papers are not so indicated.*

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PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
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Fig: 14.

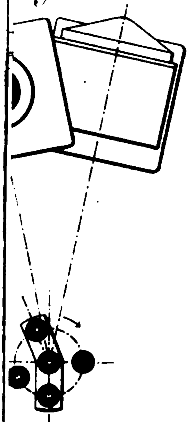
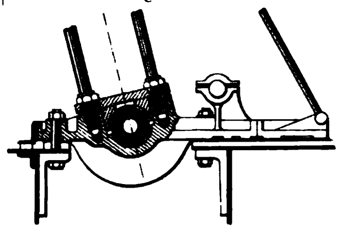
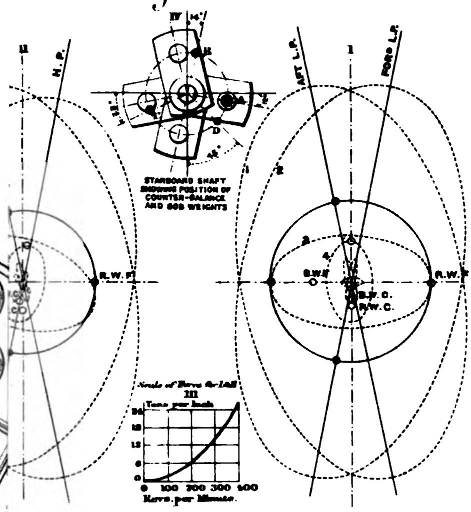


Fig: 16.



ENLARGED SECTION THROUGH BEDPLATE

Figs: 17.



TIA DIAGRAMS FOR ENGINES OF H.M.S. "DARING"

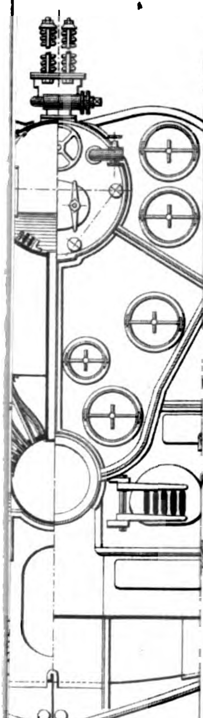


Fig: 21.

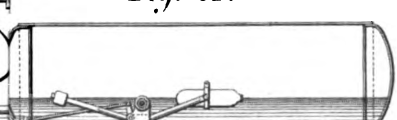
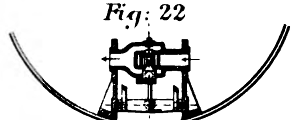


Fig: 22



ENLARGED SECTION THROUGH VALVE

THOS KELL & SON, LITH. 40, KING ST COVENT GARDEN.

CIENCY.

Fig: 7.

MECHANICAL EFFICIENCY.

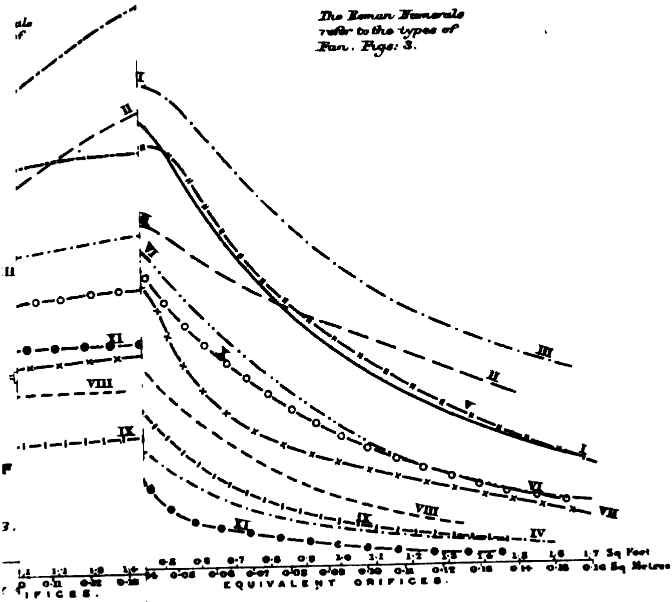
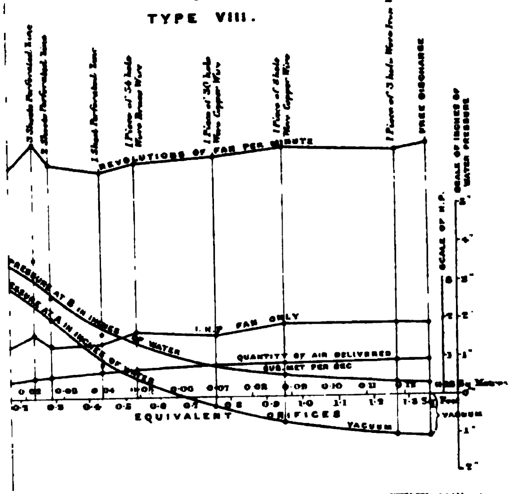
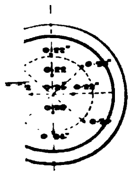


Fig: 9.

TYPE VIII.



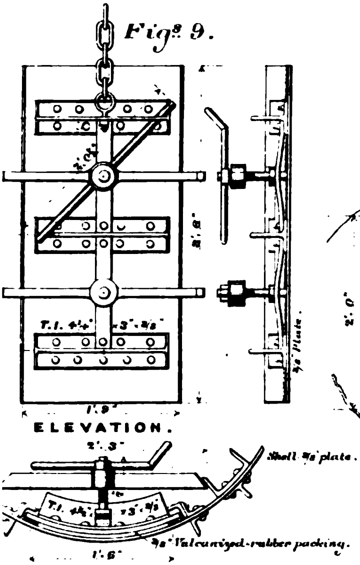


SECTION OF PIPE
PRESSURES AT
POSITIONS IN
ES OF WATER

sion 1894.

THO^s KELL & SON, LITH. 40, KING S^T COVENT GARDEN.

Fig. 9.



ELEVATION.

PLAN.

Fig: 10.

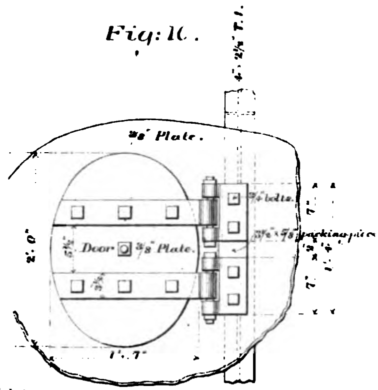
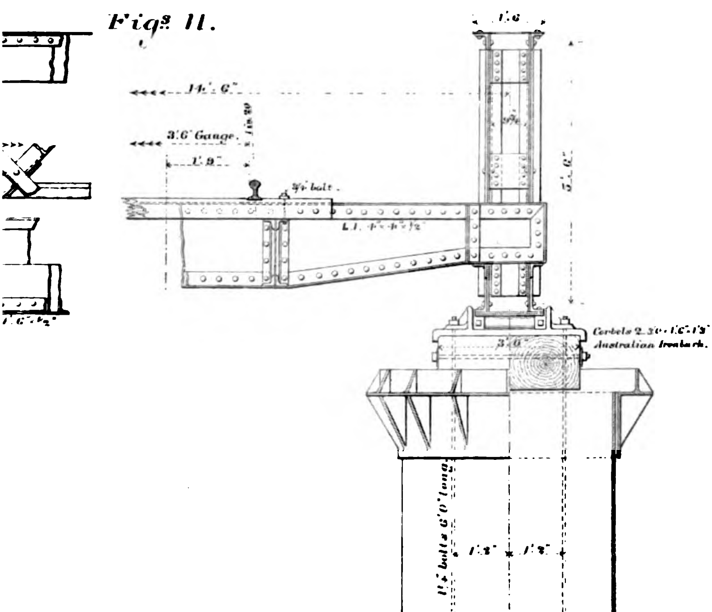


Fig. 11.



Scale for Figs. 6. 7. 8. 9. & 10.

6 0 1 2 3 4 5 Feet.

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PLATE 4.

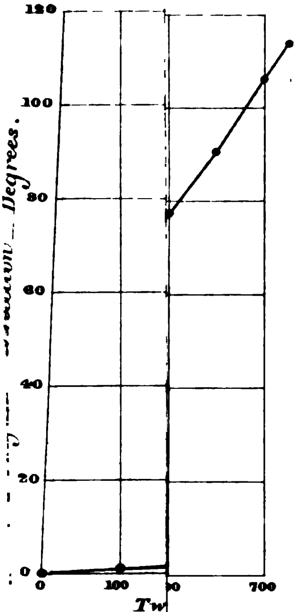
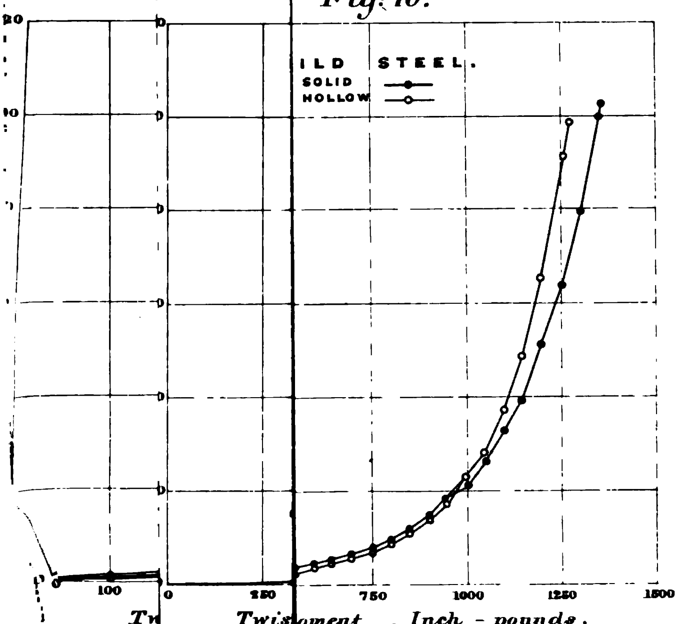


Fig: 10.



THOS KELL & SON, LITH. LONDON.